Representation of Geographic Relevance in Mobile Applications

Dissertation
zur
Erlangung der naturwissenschaftlichen Doktorwürde
(Dr. sc. nat.)

vorgelegt der
Mathematisch-naturwissenschaftlichen Fakultät
der
Universität Zürich
von

Paul Crease
aus
England

Promotionskomitee
Prof. Dr. Sara Fabrikant (Vorsitz)
Dr. Tumasch Reichenbacher (Leitung der Dissertation)
Prof. Dr. Martin Raubal

Zürich 2013

Abstract

Recent developments in technology have resulted in the appearance of mobile devices that are able to satisfy the spontaneous information needs of individuals at any time or place. This has resulted in the development of the theory surrounding the use of these devices. One consequence of this was the definition of geographic relevance, which proposes that the relevance of real world places will be heavily influenced by the geographical context of a mobile information seeker. This thesis seeks to answer a specific question related to geographic relevance – how can geographic relevance be visually represented and communicated to a mobile information seeker in an understandable and efficient way?

To provide a suitable response an approach is defined that incorporates the cognition and context of a mobile individual into the representation of geographic relevance. These two key factors provide a framework upon which to base the development of a visual representation of geographic relevance. More specifically, this approach is applied to the filtering, visual design, communication and interaction design for geographic relevance assessed information. In order to provide validation for the proposed approach three experiments were carried out. Two of these experiments focused on measuring the intuitiveness of visual variables and metaphors for encoding geographic relevance within map symbologies. The final experiment focused on looking at how the explicitness of a visual representation of geographic relevance affects the ability of an individual to understand it. The results of this work provide evidence in several different areas. Firstly, geographic relevance is tightly bound with the spatio-temporally constraints and context of an individual, and the representation benefits from the inclusion of these contextual factors. Secondly, that a cognitive approach to designing visual representations of geographic relevance has a positive effect on their ability to be easily understood.

Zusammenfassung

Neue technische Entwicklungen haben die Entwicklungmobiler Geräte begünstigt, welche spontane Informationsbedürfnisse von Individuen an jedem Ort und zu jeder Zeit befriedigen können. Daraus entstand eine Theorie, welche die Benutzung dieser Geräte untersucht. Eine Auswirkung davon war die Definition geografischer Relevanz. Diese Definiton geht davon aus, dass die Relevanz realer Orte stark vom geografischen Kontext eines mobilen Informationssuchers beeinflusst wird. Im Rahmen dieser Dissertation soll eine spezifische Frage, die mit geografischer Relevanz verbunden ist, beantwortet werden: Wie kann geografische Relevanz einem mobilen Informationssucher verständlich und effizient visuell repräsentiert und kommuniziert werden?

Um eine diese Frage fundiert beantworten zu können, wird ein Ansatz definiert, welcher die Kognition und den Kontext eines mobilen Nutzers in die Repräsentation der geografischen Relevanz einfließen lässt.Diese beiden Schlüsselfaktoren liefern eine konzeptionelle Grundlage, auf der die Entwicklung einer visuellen Darstellung geografischer Relevanz basiert. Konkret wird dieser Ansatz aufs Filtern, das visuelle Design sowie das Kommunikations- und Interaktionsdesign geografisch relevant bewerteter Informationen angewandt. Um eine Plausibilitätsprüfung für den vorgeschlagenen Ansatz zu erbringen, wurden drei Experimente durchgeführt. Zwei dieser Experimente konzentrieren sich auf die Messung der intuitiven Erkennung der visuellen Variablen und Metaphern, um geografische Relevanz innerhalb der Kartensymbolik zu verschlüsseln. Das letzte Experiment untersucht, inwiefern die Eindeutigkeit einer visuellen Darstellung geografischer Relevanz das Verständnis eines Individuums beeinflusst. Die Ergebnisse dieser Dissertation weisen in verschiedenen Bereichen auf wichtige Zusammenhänge hin: Erstens, Geographische Relevanz ist eng mit räumlichen und zeitlichen Einschränkungen und dem Kontext eines Individuums verknüpft. Zudem wirkt sich die Berücksichtigung dieser kontextuellen Faktoren positiv auf die Darstellung aus. Ein zweites Ergebnis zeigt, dass ein kognitiver Ansatz beim Design von visuellen Darstellungen der geografischen Relevanz einen positiven Einfluss auf das leichte Verständnis hat.

Acknowledgements

A well known English idiom is Elbow Grease – it is an imaginary substance that lightens a hard task. This thesis would not have been possible without large quantities of this material. However, a large part of the elbow grease necessary for this thesis was donated to the author by a large number of elbows belonging to a variety of colleagues and families. I would like to take this opportunity to acknowledge the donation of this grease to me, as without it my itchy, dry elbows would have been highly incapable of producing the contents of this thesis.

Firstly, I would like to thank the Swiss National Science Fund for funding the work, and providing me with the privilege to live and work in Switzerland. Secondly, I would like to thank the staff in the Geography Department of the University of Zurich, who helped make sure all my administrative and IT needs were catered for, suffered my bad german and took part in my experiments. Furthermore, my thanks to the GIS group staff, who organised many stimulating events, and specifically Ross Purves for the Graduate School courses that allowed me to leave my office and meet geographers who did not spend too much of their time in front of a computer.

Naturally, the greatest amount of inspiration came from my own research group – GIVA. I always looked forward to going to work with what was, and still is, a great mix of personalities and cultures. I would like to thank Anna-Katherina Lautenschutz, Jan Wilkening, Kenan Bektas, Marco Salvini, Martin Lacayo, Sara Maggi and Andre Bruggman for the friendship and support over the four years. A special mention must go to Stefano DeSabbata, my office and GeoRel project colleague for four years for his friendship, help and mutual appreciation of a good cup of 'proper' tea. I would also like to thank Dr. Arzu Çöltekin for her help, encouragement and intuitive grasp of the English sense of humour, and Professor Sara Fabrikant for her patient and expert supervision in the final year, during my experiments, and for providing extremely insightful remarks whenever asked to review my half-baked ideas and writings. Further thanks are also due to Martin Raubal for his support, revisions and insightful comments as external committee member, and Tina Sarjakoski for her role as external examiner for this thesis. Naturally I would also like to thank my supervisor Dr. Tumasch Reichenbacher, who played the most influential role in my PhD project, and my working time in Switzerland. Thank you for the (figurative) shoves in the right academic direction, patience, good humour, friendship and of course the baby clothes. Lastly, I would like to thank my wife and son for their understanding, support and ability to give me perspective.

Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Motivation

Improvements in computing, user positioning and web technologies have lead to a steep increase in the use of context-aware mobile computers. A popular category of applications developed for these systems is able to provide spatially referenced information and maps based on a user's location. Although these location-aware applications have become more prevalent, usability issues still exist that prevent them from becoming more ingrained and relevant to the everyday lives of a broad range of users. These usability issues can be seen from both a user-centred and a technological perspective. User-centred problems stem from potential information overload, limited interaction possibilities and poorly designed graphical user interfaces. One technological problem that relates heavily to these user-centred problems is that of small screens typically found on mobile devices (Oinas-Kukkinen and Kurkela 2003).

Providing only relevant information for mobile computer users has been recognised as an important step in tackling some of these problems. However, a review of mobile mapping systems by Raper et al. (2007) found that the majority of systems featured only a very basic handling of relevance. Raper (2007) was the first to propose that traditional relevance models be extended for mobile information seeking activities; this new relevance being termed geographic relevance. Raper defined geographic relevance as "*a relation between a geographic information need and the spatio-temporal expression of the geographic information objects needed to satisfy it*". Reichenbacher et al. (2009), building on the work by Raper, offered their own definition of geographic relevance, as being "*a quality of an entity in geographic space or its representation (…) expressed as the relation between the entity or its representation and the actual context of using the representation*". The basic idea behind both definitions is that geographical aspects of space and time underlying the context of the mobile information seeker should become more tightly engrained within any assessment of relevance.

This thesis is embedded within a larger research project conducted at the University of Zurich aiming at investigating the assessment and visual representation of geographic relevance in a mobile context. The content of this work is mainly the outcome of the sub-project "GeoRel: Geographic relevance in mobile applications" funded by the Swiss National Science Foundation (Grant Nr. 200021_119819 / 1). The other sub-project seeks to explore new methods in the quantitative assessments of geographic relevance for mobile information seekers

(Reichenbacher 2009b). Following these assessments each information object will have a value of geographic relevance. To fully realise the potential usefulness of geographic relevance an important step to consider is how best to model, and later, present this relevance to the user. Recent growth in the use of mobile computers has highlighted problems with the current visual representations of spatial information to users. Often these representations are not fit for the perception and decision making of mobile usage, and simply follow design rules formulated for static users (Burigat and Chittaro 2005). Using such a visual representation produces high cognitive loads which can then result in poor decision making (Raubal et al. 2004). Conversely, if representations are designed to fit in with the context and cognition of mobile usage, then usability can be greatly improved. Using attributes of system acceptability set out by Nielsen (1993), Table 1 shows how fitting geographic relevance representations to this context and cognition of mobile use could improve the usability of mobile applications.

Criterion for System Acceptability		**Benefit of GR representation**
Utility		Inclusion of only relevant information
Usability	Easy to Learn	Better legibility, less visual clutter
	Efficient to Use	Less interaction necessary
	Easy to Remember	Less information to remember
	Few Errors	Information more easily understood
	Subjectively Pleasing	Less frustrating to use

Table 1 - Usability factors and their relation to GR based on (Nielsen 1993)

At a general level, this work is motivated by the fields of geographic representation and mobile computing, both highlighted as important areas of research by the University Consortium for

Geographic Information Science (McMaster and Usery 2004). More specifically, it contributes to the research agenda of mobile computing and location based services as set out by Jiang and Yao (2006). Jiang and Yao expect that research in LBS will be best focused in a number of different areas that include a more in depth exploration of spatial cognition and visual representation, as users typically find themselves having to solve problems within geographic space (e.g. wayfinding) through the use of visual representations of space, such as maps. They also highlight space-time analysis as a potentially fruitful area of research that could add value to the contextual reasoning of mobile applications.

1.2 Research Objectives

The overall objective of this research is to develop visual representations of geographic relevance that improve decision making, and support activities of mobile users, since it is these actions that mobile devices are developed to support. Communicating the abstract concept of relevance in an intuitive and understandable manner is assumed to achieve this objective. An intuitive visual representation in this thesis is defined according to Naumann et al. (2007), as one that allows a user to incorporate previous conscious and unconscious knowledge, and thereby correctly predict what it communicates without explicit explanations being given. The main underlying thesis of this work is that the communicativeness of these visual representations can be enhanced through adaptation to the context and cognition of a user. Most research has focused so far either on the cognition or the context of mobile computer use, but to develop representations for mobile individuals requires that both are integrated into the process, so that the visual representation becomes more easily used and applied to the problems that it can solve.

To achieve the overall objective, it will be necessary to break this objective down into several smaller sub-objectives. The first sub-objective will be to communicate not just where, when and what regarding the relevance of a geographic information object, but also why a geographic information object is relevant. This will be necessary in order for the intuitiveness of the representations to be optimised. The 'why' question is perhaps the most complex, and methods to describe the reason for a geographic information object being relevant will be sought through the application of metaphors and the adaptation of spatial representations. Past research suggests that incorporating these factors will ensure that the frequently found problem of incorrectly decoding representations will be ameliorated (Habel 2003). A second sub-objective of this work will be to develop novel and intuitive methods of interacting with relevance representations that may improve the efficiency of geographic information seeking. Interacting with relevance offers a means through which users may gain insights into what relevance is and how it can aid their mobile information seeking. The final sub-objective will be to assess the ideas presented in this thesis through empirical evaluation. This thesis will also aim to provide additional knowledge to the research of visual search and map design.

1.3 Research Questions

To achieve the objectives discussed in the above section seven research questions were formulated. Research questions 1 to 4 are directed towards the exploration of the contextual and cognitive approaches for the creation of usable visual representations of geographic relevance, whilst the final three research questions are directed towards the empirical evaluation of visual representations of geographic relevance.

1. How can relevance assessed datasets be effectively filtered in order to support spatio-temporal plans and actions?

2. Which cognitive and contextual factors should guide the design for visual representations of geographic relevance?

3. Which categorisation methods are appropriate for classifying geographic relevance values?

4. How can metaphors be applied to communicate and interact with relevance?

5. Which visual variables offer an intuitive representation of relevance?

6. Can visual metaphors of relevance provide intuitive mappings to geographic relevance?

7. Do explicit visual representations of spatial relationships improve the intuitiveness of geographic relevance?

1.4 Approach

In order to answer these questions, it is necessary to develop a conceptual framework that can guide and structure the work carried out in this thesis, and this framework is the focus of Chapter 3. This framework consists of three main domains that aim to tackle the overall problem of designing effective visual representations for mobile information seeking. The main focus of this thesis will be on the representation domain, but as previous work has often highlighted, these representations should be designed according to the user's cognition (Raubal 2009) and the context of mobile use (Reichenbacher 2005a). The proposed framework shown in Figure 1 below includes all three domains, with the representation domain linking directly to the contextual and cognitive domains of mobile use.

This approach aims to allow the design of the representations of geographic relevance to be influenced by the context and cognitive states of the mobile user. The specific contextual factors that will be studied are the spatio-temporal situation, and the activity of the user, as these have been found to influence the behaviours and information needs of mobile information seekers most strongly (Sohn et al. 2008, Schwanen et al. 2008a, Raubal and Panov 2009). I propose that Time Geography and Activity Theory can provide a sound theoretical basis upon which to tackle the first research question and model a mobile user's context, which can improve the usability of a visual representation used for mobile information seeking through context aware filtering. The cognitive domain aims to explore how the design of a representation can support the visual and cognitive tasks, such as information seeking and decision making, that the representation will be employed to solve. The cognitive domain is therefore aimed at providing answers to the second, third and fourth research questions. Furthermore, this domain contains cognitive structures, such as image schemas, as they play a role in the development of intuitive map symbologies and interaction designs. This approach aims to develop methodologies that apply the cognitive and context domains to the representational domain in order to develop representations and interfaces that are usable and more useful to mobile information seekers. The remaining research questions are answered through controlled experiments, and seek to test the validity of the ideas presented in this thesis.

The outputs of these methodologies are interactive visual representations that allow a better understanding of the context within which the information seeking and decision making takes place. The overall goal of this thesis is therefore to develop and describe methods that allow the design of map representations to support the efficient and effective discovery and selection of locations that satisfy the goals of the mobile information seeker's chosen activities and the related information needs. Furthermore, although these locations can be represented as point, lines or polygons, the focus of this work will be on the representation of geographic relevance with point data. This constraint is necessary due not only to the time constraints of the project, but also to the fact that geographic relevance is in its infancy, and point of interest data represent a solid grounding from which to begin.

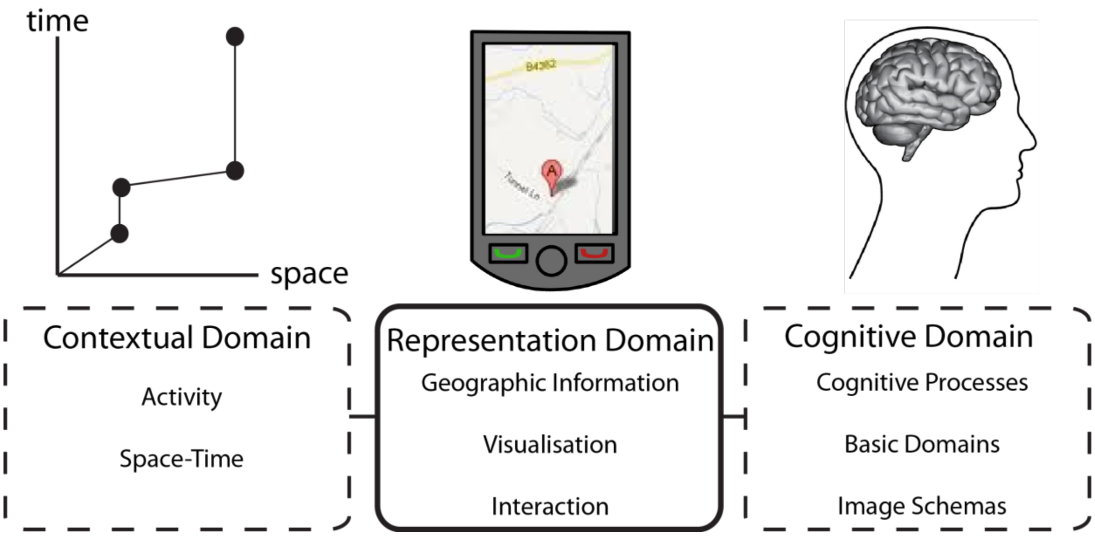


Figure 1 - Framework for the creation of geographic relevance representations (from Chapter 3)

1.5 Outline of the thesis

A broad overview of this thesis is shown in Figure 2 below, and follows the common scientific approach of reviewing relevant literature, developing methods based on this literature review, assessing these methods before finally discussing the meaning of the findings resulting from the previous steps. The theoretical context is given in Chapter 2, with a wide range of literature being drawn upon from a broad range of literature produced by the geographical, cognitive and computer sciences. Chapter 3 defines a conceptual basis for the remaining work in this thesis which draws upon the literature discussed within Chapter 2, and encompasses three domains of cognition, context and representation. The context domain from the conceptual model is then explored within Chapter 4 as a means to filter the relevance assessed datasets. Chapter 5 explains how the cognitive domain can then be applied to the data that remains from Chapter 4 in order to create efficient visual representations of geographic relevance. This chapter also includes the application of cognitive modelling tools to demonstrate the efficiencies that can be gained by the presented approach. The application of categorisation techniques and the definition of linguistic, visual and interaction metaphors are then discussed in Chapter 6, with the aim of enriching the communication and interaction with geographic relevance assessed datasets. Empirical evaluation of the ideas presented in Chapter 5 and 6 are then discussed in Chapter 7. Chapter 8 features a discussion of the main findings before an overall conclusion and description of future work is presented in Chapter 9.

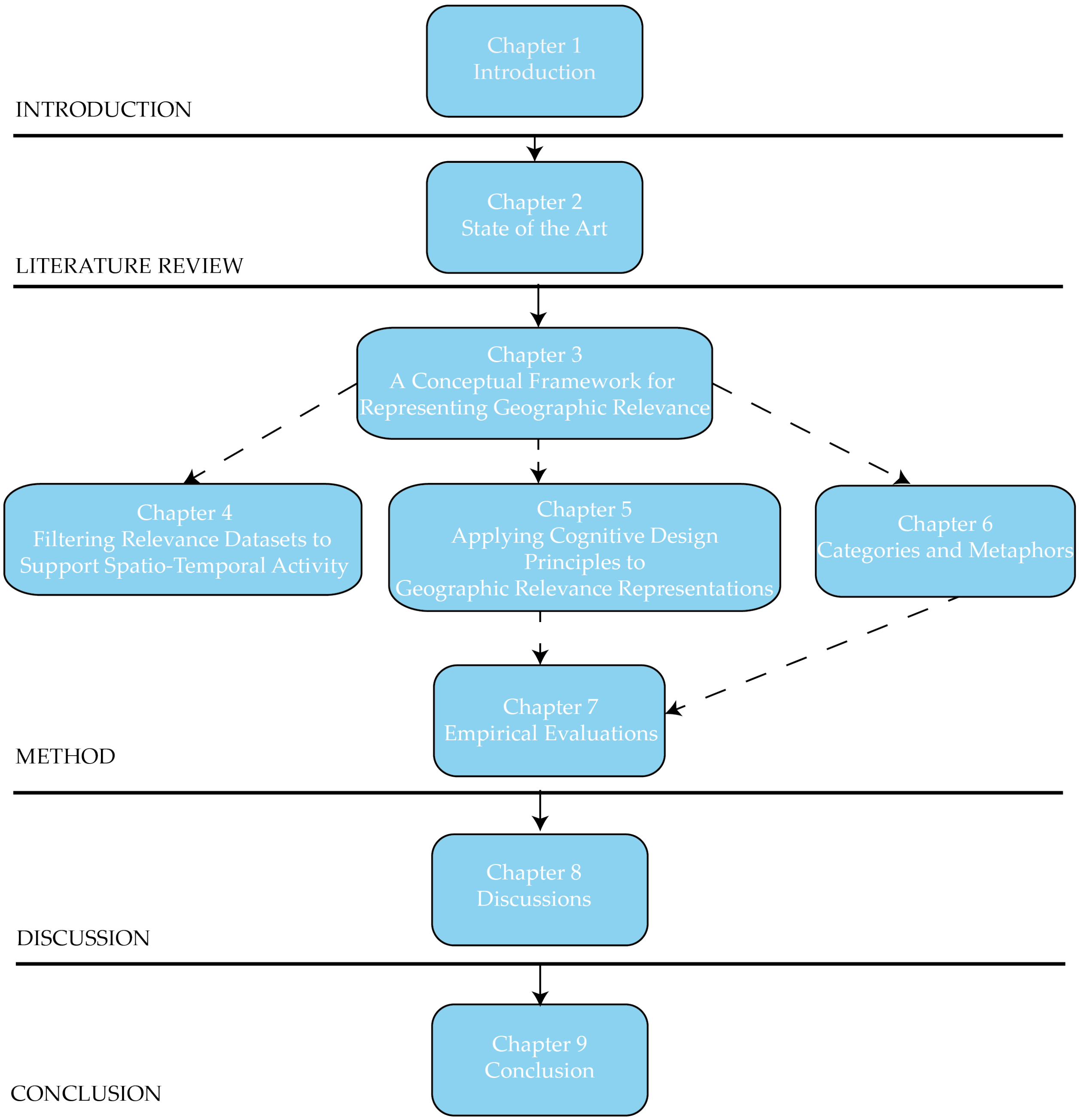


Figure 2 - Thesis structure

Chapter 2 State of the Art

2.1 Introduction

As shown in section 1.4 of the previous chapter, the theme of this thesis consists of three domains – context, representation and cognitive (as represented in the framework shown in Figure 1 of section 1.4). Fortunately, a wide body of relevant research already exists within each of these domains. This research comes from a multitude of different research fields; the majority from Computer Science, Geography, GIScience and Psychology. This chapter contains a review of the relevant literature from these fields, with the goal of exploring and describing how past work relates to the use of visual representations in mobile scenarios. It begins with the context domain, which describes research into methods that can be used to allow systems adapt to the current contextual states that surround the user during the interaction with a mobile system. Next the areas of research that relate to the cognitive domain are described. The final section of this chapter focuses on the representation domain, with reference to the research of the cognitive and context domains, and develops approaches that can benefit from the intersection of these three domains.

2.2 The Contextual Domain

Defining context for mobile individuals has proven to be complex with numerous competing definitions being put forward for consideration. Reichenbacher (2003) noted that the majority of definitions have certain things in common - they treat context as a fuzzy concept; context includes at least location, time, and user; context has static and dynamic components; context has a spatial and a temporal range. Definitions range from the general, attempting to capture a meaning of context that can be applied to all domains, to the more specific that focus on specific applications. Very broad definitions benefit from being able to encompass many different types of context but suffer from being difficult to implement in a working system, for more specific definitions this problem is reversed. The key to finding a useful definition is therefore to gain a balance between the two. An often cited general definition of context, is given by Dey and Abowd (2000), who defines context as "Any information that can be used to characterize the situation of entities (i.e., whether a person, place, or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves." Dey and Abowd (2000) then break context into primary and secondary elements, with place, time, identity and activity being the primary context elements that secondary context elements can then be inferred from.

Spatial applications must appreciate numerous different types of both qualitative and quantitative aspects of context, such as activity, location, time, history (previous locations; former requirements and points of interest), semantics (real world affordances of the information objects), user interactions and the users emotional states (Raubal et al. 2004, Nivala and Sarjakoski 2003b, Zipf and Jöst 2006, Zenghong and Yufen 2009, Sarjakoski and Nivala 2005). There are many possible contextual elements but, as Dey (2000) mentions, it is only those that affect 'the interaction between a user and an application' that should be included. This means that not all contextual elements should be included, and finding theories that can help determine which are relevant is an emerging field of research (Huang and Gartner 2008, Huang and Gartner 2011, Keßler 2012).

Numerous elements of a system can be adapted and tailored to fit with the context of a user and positively affect usability, such as how information is modelled, visualised or how it can be interacted with (Figure 3). In conjunction with the elements to adapt, numerous analytical operations exist that are able to fit the form of an element to the context of use (Reichenbacher 2003). Whilst this affords great flexibility to the system designer it also results in more variables to be considered, and therefore more thought is required as to which elements should be modified and when. However, the adaptation process should result in a mobile system being able to provide information that is relevant to the information needs of the user, and presented to them in a way that is applicable to the problem or task that they are trying to solve (Nivala and Sarjakoski 2007). This improves both the usability and the accessibility of a mobile application to individuals (Sarjakoski and Nivala 2005).

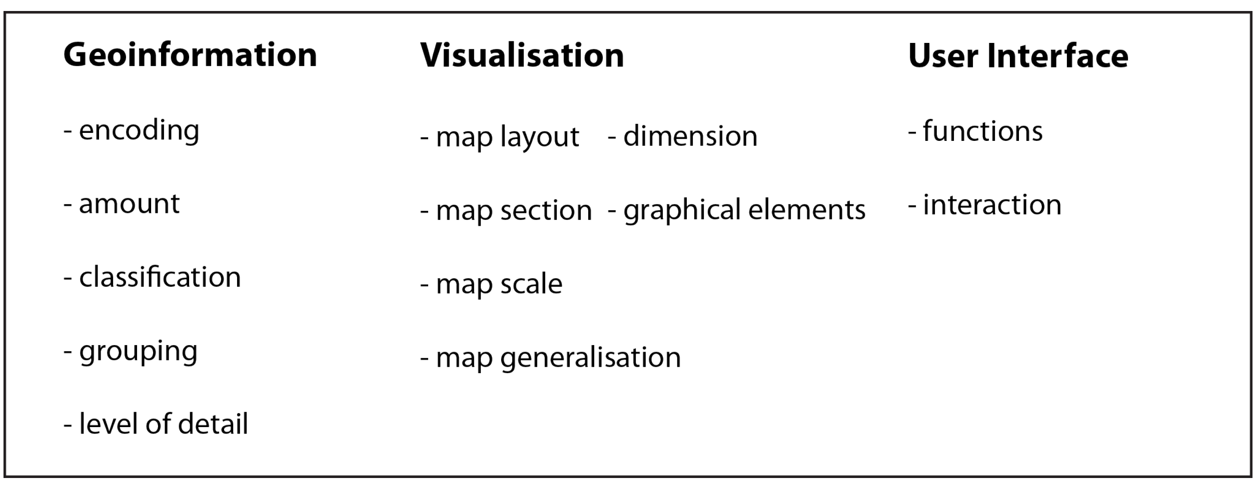


Figure 3 – Adaptable elements for geographic mobile applications (Reichenbacher 2004)

Whilst some of these operations are relatively simple to implement (making a layer visible, removing or adding tools), others are more complex (relevance assessments, altering dimensionality, change encoding). When this complexity is on a computational level, a further limitation is that most mobile computing systems suffer from slow processing units and therefore operations that carry expensive computational costs have to be avoided (Hampe and Paelke 2005). It is therefore unsurprising that until now researchers have concentrated on adapting objects which require simple operations, as opposed to the more complex ones, such as relevance assessments. A further problem is how to then formalise and organise these contextual elements. Past methods have accomplished this through configuration of system architectures to applications of linked ontologies (Zipf and Jöst 2006, Akcay and Altan 2007, Nivala and Sarjakoski 2007). Once context is formalised then the elements to be adapted can be operated on. Research here has mainly been centred on adaptation elements within the visualisation section of Figure 3. Commonly these modifications are to the digital map presentation as a whole, i.e. scale, layout, generalisation, or single information objects (2D or 3D, visual variables of map symbols) based on a user's context.

A common map adaptation is the automatic orientation of a map to the direction in which a user is travelling, this has been found to decrease the cognitive load required for map interpretation and localisation (Winter and Tomko 2004). In some respects, adapting the presentation of individual information objects has perhaps seen the most exploration of the contextual targets (Reichenbacher, 2003). An example is the use of user age groups and their preferences, which can be used to provide more understandable and acceptable map symbologies to a wider range of user (Nivala and Sarjakoski 2007, Ryan and Janet 2008). A second common adaptation is the removal of information based on contextual analyses of the mobile user (Bereuter et al. 2009). This operation can be used on the generalisation of geographic information objects overlaying a base map and the base maps itself (Zipf and Richter 2002). The aim is to leave only the most relevant information, and lower the visual and semantic complexity of the cartographic displays.

2.2.1 Spatio-temporal context

Of particular importance to the context of mobile information seeking are the limitations of space and time. Empirical studies carried out by De Sabbata and Reichenbacher (2012) discovered that spatio-temporal proximity played a fundamental role within human judgements of relevance. Furthermore, Raubal et al. (2004) argue that for mobile and location based systems, supporting spatio-temporal activity will allow them to be better integrated into the daily lives of individuals. Aside from a research perspective, the commercial world is also becoming more aware and focused on space-time analyses for trip planning and decision support, as can be seen in the recent development of services such as http://www.arrlee.eu, http://mapumental.com/ or http://www.mapnificent.net/. This therefore suggests that designing analytical procedures that can utilise the spatio-temporal context of a user will result in mobile information seeking systems that are useful and usable to individuals in their day to day lives.

From a general point of view, space-time has a large influence on our ability to make sense of the world as it limits what we can perceive and where our attention can focus (Dervin 1983). Additionally, space-time constraints also represent a limitation to the individual choices as to the activities which can be participated in (Miller 2004). This fact motivates research that attempts to analyse spatio-temporal activity in order to better understand the interrelationship between time, space and activity, and the relationships between them that can constrain or enable them (Hägerstrand 1970, Miller 2004). Much of this research has come out of time geography, which models people's movements through time and space with three dimensions (Figure 4). The x and y dimensions are the planimetric spatial dimensions, with the vertical z dimension representing time. The movement behaviours of individuals are represented by paths through space-time, which are composed of time spent travelling (travel time) and time spent carrying out an activity at a location (stay time) (Hägerstrand 1970, Wang and Cheng 2001). For a rigorous mathematical formulation of the basic structures of time geography, see (Miller 2005). Three main constraints to movement also contribute to the time geographical framework (Schwanen and Kwan 2008). *Authority constraints* are restrictions upon movements imposed by cultural and social rules, a good example of these would be opening and closing times of shops or restrictions to movements over international administrative boundaries. *Coupling constraints* limit the flexibility of individuals' choices regarding where they carry out an activity. This is frequently because the activity involves other actors, often a fixed amount of time must be spent at a location when the corresponding actors are also present at the same location. An example of this is the mandatory work hours of office work or meeting friends at a restaurant. *Capability constraints* describe limitations to the movement of an individual that result from the modes of travel which are available to that actor. For example, a family that owns a car will be able to travel further in a fixed amount of time than a family that does not own a car. Inclusion of these data and the constraints within a modelling process can then produce measures of potential accessibility. These measures aim to reflect the ability of individuals to physically move over space and reach the goals and objectives of an activity (Skov-Petersen 2001).

This simple representation of a person's movement through space and time can lead to sophisticated analyses that can answer complex questions regarding the when, where and what of spatio-temporal activity. For example, when the space-time paths and constraints are put together it is possible to define a Space-Time Prism, the spatio-temporal area that is accessible by an individual at a certain time (Thrift 1977). The Potential Path Area is the projection of the Space-Time Prism into two-dimensional geographic space.

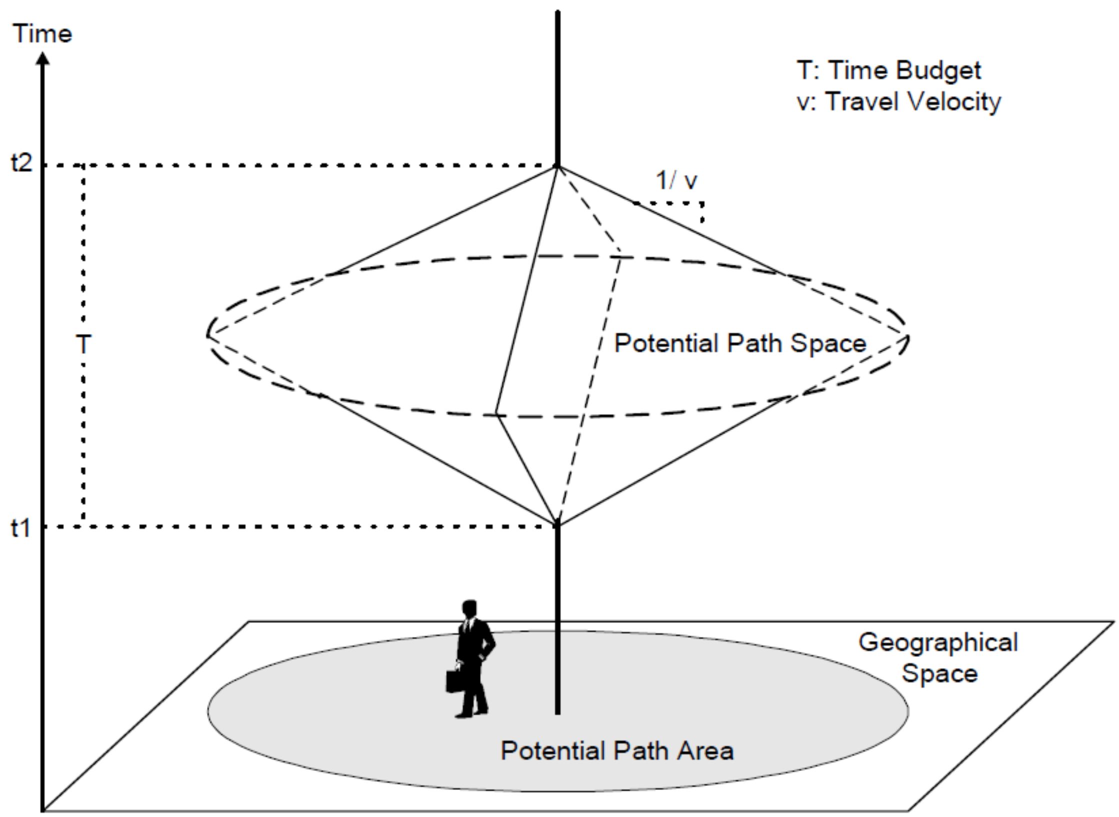


Figure 4 – Model of spatio-temporal accessibility illustrating some basic elements of time geography (Wu and Miller 2001)

An important characteristic of activity in time geography is the degree of fixity (the opposite of flexibility). This fixity can be related to either the location or the timing of the activity. The fixed activities form the backbone of the scheduled arrangement of activities over space-time, which is known as the space-time project. The remaining flexible activities are then arranged around these fixed activities. One difficulty can be in quantifying the degree of flexibility, which in the real world is fuzzy and sensitive to numerous factors (Schwanen et al. 2008b). One method to approach this problem is through the specification of fixity values for each activity arranged on a likert scale, as can be seen in the work carried out by Kwan (2000).

The main application of time geography has been in the analysis of mobile people and their activities at a group level, but their individual decision making has yet to be impacted by its core ideas (Kwan 2008, Schwanen and Kwan 2008). However, Raubal et al. (2004) proposed that time geography has the potential to offer a way for mobile systems to become more integral to the daily decisions of the individual users, and that a time geographic theory of LBS must include theories of affordances, as well as time geography. This combination of affordance and space-time then allows a mobile system to be sensitive to the preferences and possibilities that a spatio-temporal environment affords to mobile individuals. One outcome of introducing time geography to mobile applications is the ability to better support mobile decision making and the planning of spatial tasks, through the implicit inclusion of the spatio-temporal constraints in a decision support system (Espeter and Raubal 2009). These constraints allow decision making related to the spatio-temporal tasks to focus on those places and activities that are accessible or situated close to future locations of an individual (Brimicombe and Li 2006). The incorporation of preferences then allows the user to further focus on only the accessible places that fit to these individual requirements (Rinner and Raubal 2005). Aside from being able to extend functionality, evaluations of the inclusion of time geography into mobile applications has also been shown to improve the efficiency of interaction, for example, through the setting of map extents to the accessible area of a user's time budget (Raubal and Panov 2009). It has also been shown as a method through which the intentions of mobile people can be more accurately recognised through algorithms that in turn can incorporate the spatio-temporal constraints of movement (Kiefer et al. 2010). The next section goes on to explain activity context, which is also strongly related to the spatio-temporal movement of individuals (Miller 2004).

2.2.2 Activity context

Activity has been defined as a purposeful interaction between a subject and the world (Kaptelinin and Nardi 2006). It is a qualitative element of context that can represent the motivations and goals of mobile users. As activity takes place within a context, then certain contexts constrain against the performing of certain activities (Reichenbacher 2004). The activity context can be conceptualised with activity theory, which was first formulated in the early twentieth century by Russian psychologists. It is a descriptive theory that aims to extract knowledge from the interactions of humans with their external world, with these interactions being mediated through the use of tools (Nardi 1996).

Activity is directed by needs and motives and is directed towards an object. Also significant is that activities are hierarchical in structure, as shown in Figure 5. An activity can be divided into separate, lower level goal-driven actions which again can be sub-divided down into unconscious operations. Whilst activities are associated with motivations, actions are associated with goals and operations with conditions. Completion of an operation brings the actor one step closer to the goal of the action, and therefore also satisfying the motivation of the overall activity. An advantage of this structure is that activities can be focused on at different levels of detail, thereby increasing the analytical power of the framework for contextually aware systems. Additionally, an activity can be both an internal mental or an external physical process. Within this framework the division between these two is assumed to be artificial, and so both are only fully understood when considered together (Kofod-Petersen and Cassens 2006). For example, navigation devices remove the need for us to utilise our own innate abilities to navigate through space, and so the navigation activity is supported by the information processing of the system, which would otherwise take place within the navigator's cognition. Activity theory is well integrated into the field of mobile Human Computer Interaction (HCI), especially within research that attempts to define and formalise user contexts (Kaptelinin et al. 1999). Contextual information is typically interpreted from data collected from the surrounding environment by sensors. However, the external environment of the user is only one branch of context (Schmidt et al. 1999). Activity theory therefore provides a means to model the qualitative individual context by allowing representations of internal contextual information, such as user motivations, and in describing how both the individual and environmental contexts interrelate (Greenberg 2001). Application of activity theory to HCI is seen as one method to counter criticism of context-aware systems regarding the simplistic nature of contextual information often used as inputs to over-complex computational reasoning systems (Bellotti and Edwards 2001).

Implementing activity theory in a computational environment is a complicated task and often simplifications result from this procedure (Nardi 1995). However, this has not prevented researchers within the field of cartography and spatial information successfully incorporating activity theory into their work. Indeed, activity theory has been shown an effective way of providing information about the purpose of interactions with the system, clear specification of user goals, highlighting crucial context parameters, and as an effective way to model users (Dransch 2005). One popular application of activity theory is to enrich the information relating to a user's context and thereby improve the adaptations of map displays to this contextual information (Reichenbacher 2005b). Within these applications activity is modelled as an element of context or as a framework from which to discover other important elements of context. An example of the former can be found in research carried out by Raubal & Panov (2009). They built a formal model of map adaptation, using a functional programming language, within which a simplified version of activity theory was included to capture the purpose of map use. Guoray and Yinkun (2006) used activity theory as a framework to organise and structure contextual information using collaborative plans with the aim of capturing changes in context dynamically. A more qualitative approach was taken by Huang and Gartner (2008) who derived contextual parameters of a user's tasks by first looking at the activity and goals. They also demonstrated how the hierarchical structure of activity can be modelled using Hierarchical Task Analysis (HTA). In fact, HTA has proved popular within the mobile research community as a method with which to model activities, with several other studies also applying this technique (Salovaara 2004, Van Oosterom 2007, Poppe et al. 2006). A further method is to organise activities into chains of actions, although this then removes the hierarchical nature of activity that is a characteristic of activity theory (Timpf 2003).

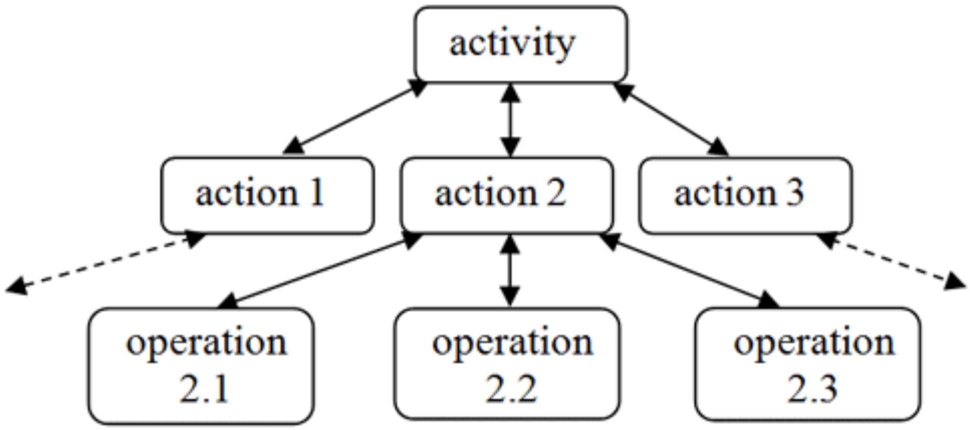


Figure 5 - Hierarchical structure of an activity (based on Kaptelinin and Nardi (2006))

2.2.3 Criticisms and Alternatives to Activity Theory

One main criticism of AT is the abstractedness of it and the difficulty in understanding the concepts it involves. This comes in part from the sometimes inelegant translation of the original dense, complex Russian texts (Nardi 1996). Also, when translating an activity into a computational environment, especially when applying Hierarchical Task Analysis, several assumptions must be made which, for some applications, can be unrealistic. These assumptions specify that there is no multitasking, activity is easily perceived, the work flow is orderly and the goals of lower level tasks do not conflict with the goals of higher level tasks (Salovaara 2004). Certainly there will be many examples of real world activities that do not adhere to one or several of these assumptions. Additionally, formalising the sequence of actions can lead to ambiguities because one activity can be formed from many different sequences of events (Kiefer and Schlieder 2007). This adds a degree of subjectivity when forming the hierarchical structure of an activity.

Other theories have emerged to allow a less structured perspective when studying context, such as the theory of Situated Action (Greenberg 2001). Situated Action suggests activities are driven by improvisation and responsiveness to a situation and the environment of a user; goals are only formulated after the action has occurred as a means of rationalisation. Also, lower level unconscious operations become more relevant and broad activity patterns, such as routine, are not included. However, in a comparison of both theories, Nardi (1995) concludes that it is activity theory that offers the richer framework for explorations of context. Furthermore, for mobile scenarios the goals of the user are formed during planning phases and thus activity theory provides the better model of activity.

2.3 Cognitive Domain

2.3.1 Cognitive processes in mobile map use

Technology plays an important role in the support of human cognitive processes in the solving of problems. This is especially true for location aware technologies which are frequently used to solve complex spatio-temporal problems (Seifert et al. 2007). One way to define problems is as actions that are difficult to carry out, with the solving being a task undertaken by cognitive processes which must design and execute a plan of action (Drew 1978). The contextual domain has a role to play within the cognitive domain, because the nature of the problem that must be solved is defined most often externally to us by the environment within which we find ourselves. This environment has an influence on the degree of complexity that the problem represents and thus on the limited cognitive capacities that must be brought to bear on it (Simon et al. 1987). The individual components of human cognition that must be utilised, in order to solve the particular problem or task presented to us, will therefore also be determined by the external environment (Payne et al. 1990, Simon 1972). In mobile settings, the environment has a large influence upon the interactions of a user and makes several unique demands on the cognition of an individual not found in static settings. Firstly, it is often the spatial cognition that must be focused on the task at hand, for example performing mental rotation of visual representations or storing the spatial structure of an environment (McNamara et al. 2003). Secondly, in mobile settings the cognitive resources of an individual are more limited than in static settings due to the opportunity for disturbance and distraction such as loud noise or bright light (Burigat and Chittaro 2007, Schmiedl et al. 2011). To deal with this complexity mobile mapping technologies can act as tools to extend our cognition (Norman 1991). Discovering exactly how these technologies affect our cognitive processes has been motivated in recent times by several research agendas in the fields of geo-visualisation and spatial representation (Yuan et al. 2004, MacEachren and Kraak 2001).

Mobile mapping system can extend users' knowledge of the surrounding environment, act as an external store of spatial information and remove the need for spatial cognitive processes to be employed during wayfinding tasks (Meng 2003, Freksa et al. 2005, Huang et al. 2012). This external store of spatial information is then used as input to our cognitive processes during the map reading process. In fact, the map reading process engages several levels of cognition, from the low levels that sense the different colours and shapes of objects within the map, to the higher levels that help us understand the meaning behind these differences (Lloyd 1997). Maps also influence and stimulate the development of spatial knowledge within our own minds, through the ability to represent spaces that our own senses cannot manage to perceive (Uttal 2000). Research into mobile map use has often looked into how spatial information is represented, and how the representational scheme chosen affects the ability to perform spatial tasks (Kray et al. 2003, Dillemuth 2005, Wunderlich and Auer 2008, Oulasvirta et al. 2009a). Results from these studies suggest that being able to adapt the representations to support the mental tasks of an individual produces a more usable map. This usability results from the map lowering the cognitive load of performing a given task, as less information has to be processed within the cognition of the individual (Bunch and Lloyd 2006).

A cognitive engineering approach aims at solving exactly this problem, with technologies designed according to the theories and knowledge originating in the field of cognitive science and psychology (Norman 1986). In a spatial setting, discovering ways to adapt the maps to the cognitive tasks and states of a mobile user is one focus for research into the cognitive engineering of geographic information. Furthermore, the task of cognitively engineering geographic information can only be achieved through further research into the definition of human conceptualisations of space, spatio-temporal decision making, context and evaluating prototypical implementations of mobile systems (Raubal 2009).

2.3.2 Information Seeking

Research into information seeking has focused on developing theories and models to explain why and how people seek information and what information they need to meet a defined goal (Wilson 1997). These models and theories can then in turn be applied to the creation of better information retrieval techniques, although Saracevic et al. (1997) note that this is rarely the case. Often system design is based only on common sense principles. A core part of designing information retrieval systems, which aids the efficiency and effectiveness of the information seeking process, concerns the concept of relevance. Within Information Science Saracevic (1996) perhaps provided the most comprehensive definition of relevance consisting of five manifestations of relevance - algorithmic, topical, cognitive, situational and motivational. This concept was extended into the geographical realm through Geographic Information Retrieval (GIR), which explores the development of information retrieval systems that could incorporate the spatial scope of documents and queries into their relevance assessments (Jones and Purves 2008).

Whilst the research above focused on the information seeking of a static individual, the introduction of mobile systems has created a new set of problems, resulting from the dynamic context of the user and technological limitations of these devices in the context of decision making (van der Heijden 2006). GIR was extended into mobile settings through the incorporation of the user's physical location into the information retrieval process, Mountain and MacFarlane (2007) termed this Mobile Information Retrieval (MIR). For mobile users, Raper (2007) argued more than just location was necessary and that the key geographical components of geography, space and time, should be incorporated into an extension of the situational relevance dimension first specified by Saracevic (1996). This extension of situational relevance is required to support the information seeking of mobile individuals which becomes more geographically oriented when compared to desktop users (Mountain and MacFarlane 2007). Space and time become important criteria for relevance judgements of mobile users because information seeking becomes more motivated towards real world entities rather than informational entities (Coppola et al. 2004). Translating space and time into relevance criteria has resulted in many new geographical relevance criteria (Figure 6 in italics), which have been subsequently verified empirically (De Sabbata and Reichenbacher 2012).

Properties	Geography	Information	Presentaion
topicality	spatial proximity	specificity	accessibility
appropriateness	temporal proximity	availability	clarity
coverage	spatio-temporal proximity	accuracy	tangibility
novelty	directionality	currency	dynamism
	visibility	reliability	presentation quality
	anchor-point proximity	verification	
	hierarchy	affectiveness	
	cluster	curiosity	
	co-location	familiarity	
	association rules	variety	

Figure 6 - Criteria of geographic relevance, from De Sabbata (2010).

Current implementations have focused on the supporting of these information needs by applying a variety of filters that are parameterised based on contextual information (Mountain and MacFarlane 2007, Bereuter et al. 2009). A second notable method was proposed by Carmo et al. (2008), who created a Degree Of Interest function that took distance, time and semantic measures in order to find and remove irrelevant information. All these approaches share a commonality; to limit the information presented to the user, and to mitigate against the negative characteristics of mobile use, for example, disturbances from the surrounding environment and small screens, both of which place more pressure on the limited cognitive resources of the user.

2.3.3 Decision Making

As situational relevance of information can also be defined as the usefulness to decision making, it is also important to consider the decision tasks within the system design process (Saracevic 1996). Decision making can be defined as the process of choosing and evaluating alternative solutions to a problem (Simon et al. 1987). Decision making processes are conceptualised within decision making theory to operate upon alternatives, with each alternative possessing a range of aspects upon which it can be evaluated. With this in mind, the new concepts of relevance discussed in the preceding section can be used as a means to support a decision, with each alternative being evaluated by comparison of relevance criteria. A common means to support spatial decision making is with the use of a decision support system (Crossland et al. 1995). Spatial decision support systems have seen continual developments, from mainframe computers for government and business (Densham 1991) to mobile systems for individuals (van der Heijden 2006). In a mobile context, spatial decision systems are used to guide the primary activities of groups or individuals (Espeter and Raubal 2009, Häubl and Trifts 2000). Furthermore, the context within which these mobile decisions take place is often time pressured, with the impact of the decision felt soon after it is taken (Reichenbacher 2003, Achatschitz 2005). This time pressure places extra demands on the decision making process of the individual (Wilkening and Fabrikant 2011) , and therefore results in the design of the mobile decision support system needing to be carefully considered and adapted to these mobile situations (Reichenbacher et al. 2009). Another crucial aspect of mobile decision making is the type of decision task that a mobile individual might perform. Golledge and Stimson (1997) describe a typology of possible spatial decision tasks :

- *uncomplicated choice among limited alternatives* e.g. which road is quickest;
- *complex choice situations* e.g. incorporates beliefs, attitudes and preferences;
- *temporal choice* e.g. what time should I arrive?
- *variety-seeking behaviour* e.g. finding possible or new activities;
- *simulation of complicated choice outcomes* e.g. what if we do X instead Y?

Raubal et al. (2004) suggest that the first three of these apply to mobile users involved with spatial decision making, but in some scenarios it could be argued that the fourth can be thought of as relevant. Aside from the different types of decision tasks that exist, many different types of user groups with different skill sets will be utilising these mobile systems (Raubal 2009). This has resulted in spatial decision support systems for mobile users possessing a simple, lean interface design, and often being personalised to the user's needs and preferences (Rinner et al. 2005, Bäumer et al. 2007).

2.4 Representation Domain

2.4.1 External Spatial Representations

Everyday activities require geographic problems to be solved, and external visual representations of space, such has maps, displayed on mobile systems represent tools that can help individuals solve these problems. A general definition of external representations, provided by Zhang (1997) and shown below offers a broad definition of external representations.

"external representations are defined as the knowledge and structure in the environment, as physical symbols, objects, or dimensions (e.g., written symbols, beads of abacuses, dimensions of a graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.)."

To geographers spatial representations are digital descriptions of spatial concepts regarding entities, relationships and processes mapped into an external symbolic form (Raper et al. 2002). Forming external spatial representations commonly follows three clearly defined phases of abstraction that start with an abstract model of reality, moves on to defining a data model of the abstraction and ends with a digital representation, such as a file or database table (Peuquet 2002). This process forces the modeller to simplify because reality is infinite and continuous and computers are discrete and finite (Longley et al. 2005). From a conceptual viewpoint, several divisions exist. Perhaps the most fundamental is whether a concept (e.g., crime) or a phenomenon (e.g, volcano) will be represented. This division has not only been highlighted within the fields of Cartography and GIScience (MacEachren 1995, Smith and Varzi 2000), but also been found to be intuitively understood by naive participants of empirical studies (Smith and Mark 2001). Furthermore, this difference is most likely relevant to another division in conceptual spatial representation, which defines if the spatial extents of a representation are fuzzy or crisp. Couclelis (1996) tried to conceptualise this division by forming a three-dimensional typology of factors that influence the fuzziness of boundaries.

Recent research into spatial representation has mostly focused on a third division, the field-object duality. Although recognised earlier this duality was more concerned with implementation and known as the raster vs. vector debate. Couclelis (1993) suggested that these terms were restrictive and offered a view from a more philosophical and cognitive viewpoint, drawing on the concepts of atomic and plenum first discussed by ancient Greek philosophers

(Moellering 2003). These two fundamental concepts now became two different ontologies by which to conceive the world rather than simply two different data models (Peuquet 2002). Important in the definition of the field and object concepts are locations, and attributes (Galton 2004). Locations are positions in two or three dimensional space and attributes are measurements of some phenomena at a location. In the field view every location is associated with a set of attributes, in a sense the value of the attribute is a function of the location (Cova and Goodchild 2002). This function of location is a continuous one and the attributes can also possess this property. In the object view the location and attributes are a function of the object; they are effectively properties of the object. Within this view the locations, and therefore space, are discrete and the attribute values are constant over space. Although some phenomena are naturally perceived as being best represented by either object or a field views, others are not so easily categorised (Peuquet 2001). When faced with the task of representing these more complex phenomena then a choice must be made regarding which view is most applicable. Bian (2007) discussed five key factors that influence which view offers the best fit (Table 2). This approach suggests the person forming the representation must make a choice between the two methods of spatial representation but recently some arguments have arisen that suggest otherwise. These arguments express the contention that overlaps between the two views exist, for example through the calculation of density fields from objects or algorithms that extract objects from fields based on their attribute values, and that unification at the logical phase of modelling is possible (Goodchild et al. 2007, Voudouris et al. 2005).

Conceptual Criteria	**Object**	**Field**
Spatial Scale	Small Scale	Large Scale
Boundary	Crisp	Fuzzy
Process	Discrete	Continuous
Attribute	Sharp Change over Space	Gradual Change over Space
Mobility	Punctual	Areal

Table 2 - Criteria that influence a conceptualisation as object or field. After Bian (2007)

In the domain of information seeking, GIR and geographic relevance, some work has already been carried out with the aim of visually representing the non-visual concept of relevance. Representing the similarity of web documents in a cartographic space that can support and improve the browsing experience has already been tackled extensively within the field of

Spatialization (Skupin and Fabrikant 2003). Applying the same techniques to geographic information retrieval portals has involved visualising the dataset vector space underlying the relevance calculations (Hobona et al. 2006). Of course, portraying the vector space model so literally would be difficult for systems that assess documents along more than three dimensions, and as geographic relevance is concerned with more than three dimensions this approach is not suitable. However, there has also been some work carried out for the representation of characteristics analogous to geographic relevance, examples of these are shown in Figure 7. Typically in this domain a cartographic representation is utilised, with visual

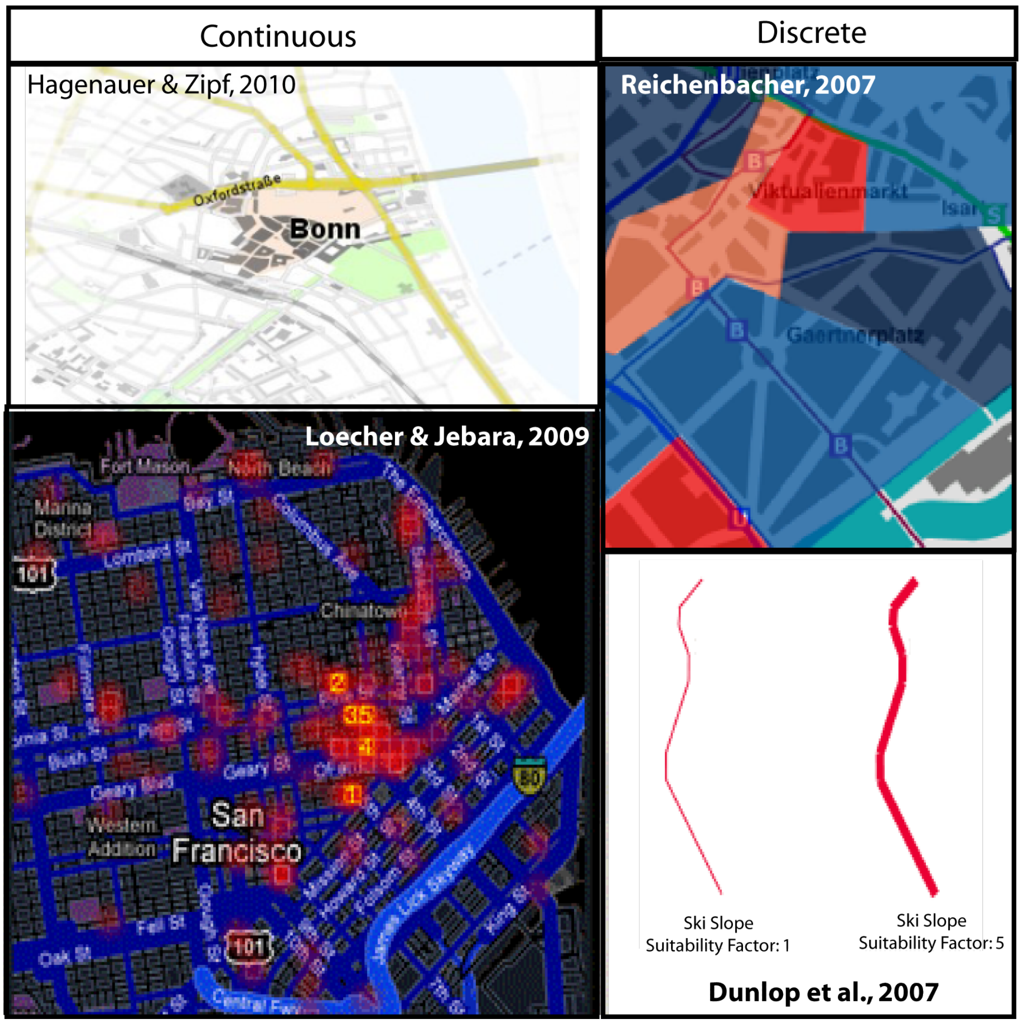


Figure 7 – Examples of visual representations of relevance

variables being mapped to relevance values of geographic information objects that overlay a spatial reference layer, examples can be found in work by Dunlop et al. (2007) in the suitability of ski slopes as linear objects, and utilised line thickness as a visual means of communication. Reichenbacher (2005b) explored relevance in the context of mobile map adaptation, and discussed the visual representation of relevance for punctual, linear and areal objects. Whilst these studies focused on visualising a single combined value of relevance, Burigat et al. (2007) explored how to represent the match between an object's attributes (cost, distance etc.), and the user's query through the incorporation of bar charts into map symbols. There has also been work carried out into the representation of less crisp objects. In keeping with the conceptual criteria shown in Table 2, this work has typically employed vague boundaries when relevance results for continuous, gradually changing spatial characteristics, such as density (Loecher and Jebara 2009).

A second more implicit approach to the definition of relevant areas with vague boundaries is through the linking of a map objects transparency or level of detail to its distance from a relevant area (Zipf and Richter 2002). This approach, known as focus mapping, then allows a gradual decrease in saliency with distance, and therefore communicates a fuzzy extent of relevant areas (Hagenauer and Zipf 2010).

2.4.2 Visualisation and Interaction

Many of the visual tools that are currently used to understand data were developed in the last 300 years to replace large numerical tables that were often difficult to interpret (Tufte 1985). If the visualisations are not properly designed then often vital information can be missed, become more difficult to understand, or will simply be misinterpreted by the users (Shah et al. 1999). These problems have led to research fields that focus on finding efficient methods to visualise and interact with visual forms of information (Thomas and Cook 2006, Bertin 1983). A common way to visually represent spatial information is by cartographic representations. This is especially true of mobile information seeking, because the information needs are most often related to the geography of the user, and therefore maps offer a natural way to communicate many qualities of spatial relevance (Raper 2007, De Sabbata and Reichenbacher 2012). To support these mobile information needs, mobile visualization research has mainly focused on finding methods to depict map symbols that can communicate the degree to which that information object meets a user specified query (Carmo et al. 2007). These methods typically deal with the technical problems brought on by the mobile context of small screens, such as visual clutter (Burigat and Chittaro 2005), or directly tackle the cognitive user-centred problem this creates of limited visual attention (Swienty et al. 2008b). Apart from the amount of visual information, the form that this information takes has also been a subject of research. Often an egocentric perspective within mobile map visualizations is pursued, through the development of three dimensional cartographic representations (Nurminen 2006) and augmented reality techniques (Höllerer and Feiner 2004).

The visualisation research discussed above addresses the limited visual attention of a mobile user, but also important is the interaction with the map, as mobile users also possess limited interaction possibilities (Nivala and Sarjakoski 2003a). Recommendations from empirical studies of mobile information seekers often advocate the design of mobile interfaces that can lessen the requirement for direct interaction, such as scrolling or zooming (Jones et al. 1999). This offers a challenge to mobile map design as zooming and panning operations are important interactions with which the user can gain contextual information and develop spatial knowledge from the map (Dillemuth 2009). This challenge has been met with the introduction of fisheye focus+context interfaces, the integration of panning and zooming into a single interaction and metaphors to display off screen information (Cockburn et al. 2009, van Wijk and Nuij 2003, Sarkar et al. 1993, Baudisch and Rosenholtz 2003). Simplifying the visual appearance of the interface is also a common design goal when developing mobile information seeking (Schilit et al. 2002). This last point is especially relevant for mobile map interfaces that must support information seeking because maps can be visually very complex when displayed on small screens, resulting in visual clutter (Edwardes et al. 2005). Further research has tried to lessen the number of different zoom levels available to a user, so that fewer interactions must be carried out when moving between map scales (Cheung et al. 2009).

One problem for map users is the unique interaction possibilities, such as panning and zooming that map interfaces offer. This leads to the mobile map users having to become familiar with these interaction methods, something studies have shown to be challenging for the naive user of a mobile map (Riegelsberger and Nakhimovsky 2008). As both of these interaction methods are important when searching the map space for relevant objects, this therefore presents itself as a challenge to a system designer (Elzakker et al. 2007). This challenge, when approached from a cognitive engineering perspective, arises because the user is not able to translate his or her psychological variables, i.e. goals or tasks, into the physical variables, which in the case of a mobile map is dragging (panning) and pinching (zooming) the touch screen. Norman (1986) described this mismatch as a 'gulf of execution'. This gulf can be bridged by the designer moving the physical variables closer to the psychological variables. The challenge lies in finding design methods that allow the construction of this 'bridge' through the development of an intuitive interface.

Several directions exist that allow this bridge to be produced and allow a user faced with a fundamentally unfamiliar interaction possibility to intuitively grasp what is required, in order for them to manipulate the interface correctly, and solve their task. A popular method is through the incorporation of affordances, as first defined by Gibson (1977) in the field of perceptual psychology. An affordance is defined as what one system provides to another system (Fadel 2009). In the field of mobile maps, Meng (2008) offers a list the affordances offered by maps to their users, which ranges from the aesthetic to the practical. Norman (1999) introduced this concept into the realm of visual interface design and described how an interface can be designed to intuitively suggest what interactions are possible, and termed this a perceived affordance. A second approach is through the appreciation of heuristic design rules which aim to give a general set of guidelines with which system designers can improve the usability of their system (Nielsen 2002, Bearne et al. 1994). These guideline offer a quick, easy method with which to improve the usability of a mobile application (Gong and Tarasewich 2004), although incorporating these lists of guidelines can be complex if they are composed of many items (Keevil 1998).

2.4.3 Metaphors

Finally, the use of metaphors is seen as an applicable method to make unfamiliar interactions and visual representations intuitively understood that is often applied to design of both static and mobile interfaces (Krüger et al. 2007) . In linguistic terms, metaphors allow us to easily communicate abstract concepts to one another by taking something familiar (a source domain) and mapping it to something unfamiliar (a target domain) (Lakoff and Johnson 1980). This can be seen in the work by Maglio and Matlock (1998), where information seekers using the world wide web described their interactions in terms of physical motion through a space. Human computer interaction research was swift to highlight the suitability of metaphors to interface design, where the abstractness of interface elements must be made understandable. It has been observed that people tend to learn new things by making use of their past learning and it is this fact that gives metaphors the ability to improve interface intuitiveness (Carroll and Thomas 1982). This research resulted in the windows, desktop and folders metaphors that we commonly use today as a visual interface to numerous operating systems (Smith et al. 1987). Metaphors have been broadly categorised in the field of information science into those that help structure information, those that allow direct manipulation of information and those that allow navigation within the information space (Vaananen and Schmidt 1994). Past research into metaphor use in the spatial domain has focused on all three of these metaphor types. A good example of the manipulation and navigation metaphor for mobile spatial applications is the tour guide system that incorporated the functionality of a web browser (Dix et al. 2000). Kuhn proposed the direct manipulation of spatial information, typically carried out through the use of a geographic information system, could be supported by creating interface metaphors based around cognitive linguistic theories (Kuhn 1993). Another good example is in the extension to the categories of Vaananen and Schmidt, as introduced by Reichenbacher (2005b). He proposed that metaphors could not only be used to benefit interaction, but also be introduced as a means of visually communicating the relevance of map objects. Visual metaphors have also been employed to communicate the spatial imprecision of the user's location when displayed on a map, for examples of these see the review by Baus et al. (2003).

2.5 Summary

Technological developments in mobile and location based services take place constantly, and with them more becomes possible during the design of these systems. These technological developments can be better graphical interfaces, new methods of low-level interaction or improved sensor capabilities to capture context. A common approach in this case would be to use existing or develop new theory to understand how these new technologies can be made useful to a mobile computer user. However, this thesis deals with the exact opposite of the problem above. Geographic relevance is a step forward in the theory underlying these mobile services, and as such the design phase must take account of this new theory, and look at how existing visualisation and interaction techniques and theories can be applied in order to make it useful to mobile individuals seeking information.

This chapter discussed the past research and theory from a range of perspectives that are strongly related to this new theory of geographic relevance. It was structured according to the three domains of context, cognitive task and representation, which make up the main components of the conceptual framework for developing visual representations of geographic relevance. Literature suggests that for information seeking of mobile users, these three domains are tightly bundled together and therefore the conceptual and technical work involved in developing a representation process should be informed by the context and cognition of the user of a representation (Raper 2007). Until now, the development of relevance representations has focused more on either the cognition or the context of the user, but not on a synergy of both, and this results in a need to develop methods that can incorporate both of these into the development of mobile visual representations and interaction methods (Bian 2007).

This literature review suggests that there are many existing theories of cognition and context that can be integrated into the developments of visual representations, and thus enhance the ability of a mobile information seeker to intuitively recognise and understand the constraints and opportunities that exist within the surrounding geographic environment. Unfortunately, no clear concept regarding the development of visual representations of relevance or user interfaces that can aid mobile information seekers exists. This is especially the case for geographic relevance and for various reasons. The main reason is that the concept of geographic relevance has only recently appeared, with perhaps the first use of the term being used by Mountain (2005) in his PhD thesis, the use of which he relates to earlier work from Raper (2002). However, the term and the concept underlying it was not fully introduced until later (Raper 2007) and therefore the freshness of this new idea has meant it has only recently begun to be more fully explored. A second reason for the lack of conceptual basis for its visual representation is that most work in this area has focused on how to calculate the values of relevance, rather than how these values should be visually represented. Notable exceptions can be found in the work by (Reichenbacher 2005b) and (Swienty 2008), who presented a list of visual variables that could be used to visually encode relevance into map symbols. However, this work is more focused on how to visualise the relevance, and building a representation consists of more than just the basic visual appearance of map symbols. Therefore, there is a need to develop a conceptual methodology that can be applied to the development of representations of geographic relevance. This description of this conceptual framework will be the subject of discussion in the next chapter.

Chapter 3 A Conceptual Framework for Representing Geographic Relevance

The previous chapter discussed the past research from a range of perspectives and addressed several theories which relate and explain the information seeking behaviours of mobile individuals. It was structured according to the three domains of context, cognitive processes, and representation. The aim of this chapter is to define the concepts of these three domains within the scope of this thesis. All of these domains have a role to play within the methodology applied in this thesis to develop representations of GR, and the form they take will have an influence upon this exact nature of this role.

3.1 Conceptualising the Context Domain

As shown in the previous chapter, numerous sources of information exist that can define the context of a mobile individual. The context focused on within this thesis is the spatio-temporal activity of the mobile individual, as previous research has shown these elements of context to be the most influential to mobile information seeking (Sohn et al. 2008). An initial definition of activity for mobile individuals can be found in Reichenbacher (2004), who defines activity as "*a motivated sequence of coherent actions carried out at a specific location for a certain time*". However, several methodological differences exist in the approach presented in this thesis that result in this definition requiring enrichment, from theories of space-time, activity and action. Therefore activity is conceptualised in this thesis with the inclusion of several important characteristics from past research. These characteristics are discussed below.

3.1.1 The hierarchical structure of activities

A key role in the description of activity is the hierarchical structure that allows the analysis to be employed over multiple scales and in different amounts of detail. The top level of the hierarchy is *activity* which consists of *actions*, which in turn consist of sub-conscious operations. An example of an operation would be turning a door handle or pressing a button to achieve the task of opening a door. This detail is also reflected in the reasons for the activity with a motivation of the activity being represented at the action level with specific goals and at the operation level with conditions. The progression of activity continues in a depth first fashion, with the first operation leading to the second operation, which eventually leads to a completion of the first *action*. Operations within the next action are then carried out and this process carries on until all actions are completed. The atomic element of *activity* in this thesis will be SubAction. The most detailed level of activity theory is operation level but this encompasses routine unconscious action and therefore offers too much detail for our model. These SubActions represent the most basic elements of spatio-temporal activity as being either a movement towards a location where activity is carried out (travel SubAction) or as time spent carrying out the activity (stay SubAction) (Wang and Cheng 2001). Therefore a Sub Action is defined here as:

$$\text{SubAction}=(\text{location}^{\text{start}},\text{location}^{\text{end}},\text{time}^{\text{start}},\text{time}^{\text{end}})$$

Where

$$\text{SubActionType} = \text{Stay IF location}^{\text{start}} == \text{location}^{\text{end}}.$$

$$\text{SubActionType} = \text{Travel IF location}^{\text{start}} <> \text{location}^{\text{end}}.$$

An action is then defined as a collection of one or more travel and stay SubActions $\{\text{SubAction}_1\ldots\text{SubAction}_n\}$ related by a common theme (shopping, socialising). This common theme results in the information needs being directed to GIOs with a similar category type (for example, shops or bars). The highest level of Activity is then an amalgamation of all the separate actions $\{\text{Action}_1\ldots\text{Action}_n\}$. This then results in a hierarchical structure, built up from travel and stay movement behaviours that occur over space-time.

3.1.2 The acting and planning notion of activities

Based on the theories of action reviewed in the literature, we further add to the definition of activity by conceptualising it as a two-phase process. The first phase is a planning phase, the second an acting phase, with the first typically occurring before the second. A mobile information seeking system should be sensitive to both phases of an activity, if the whole of the information seeking process associated with a given activity is to be holistically supported. From a spatio-temporal activity perspective, in an acting phase the information seeking process is carried out at the same time and place as the resultant action. In a planning situation, a spatio-temporal separation will occur between the end of the information seeking process and the beginning of the resultant actions. This definition is graphically shown on a space-time graph in Figure 8. This leads to the observation that when planning, the start of the activity is disjoint from the information seeking process in space-time. This means that the context within which these actions will eventually take place is uncertain. When unpredictable changes in context occur during the acting out of a plan, such as late trains or bad weather, then information needs may arise that need to be acted upon immediately (Cai and Xue 2006). Additionally, information seeking during the planning phase will also be focused on fixing a time to carry out the activity.

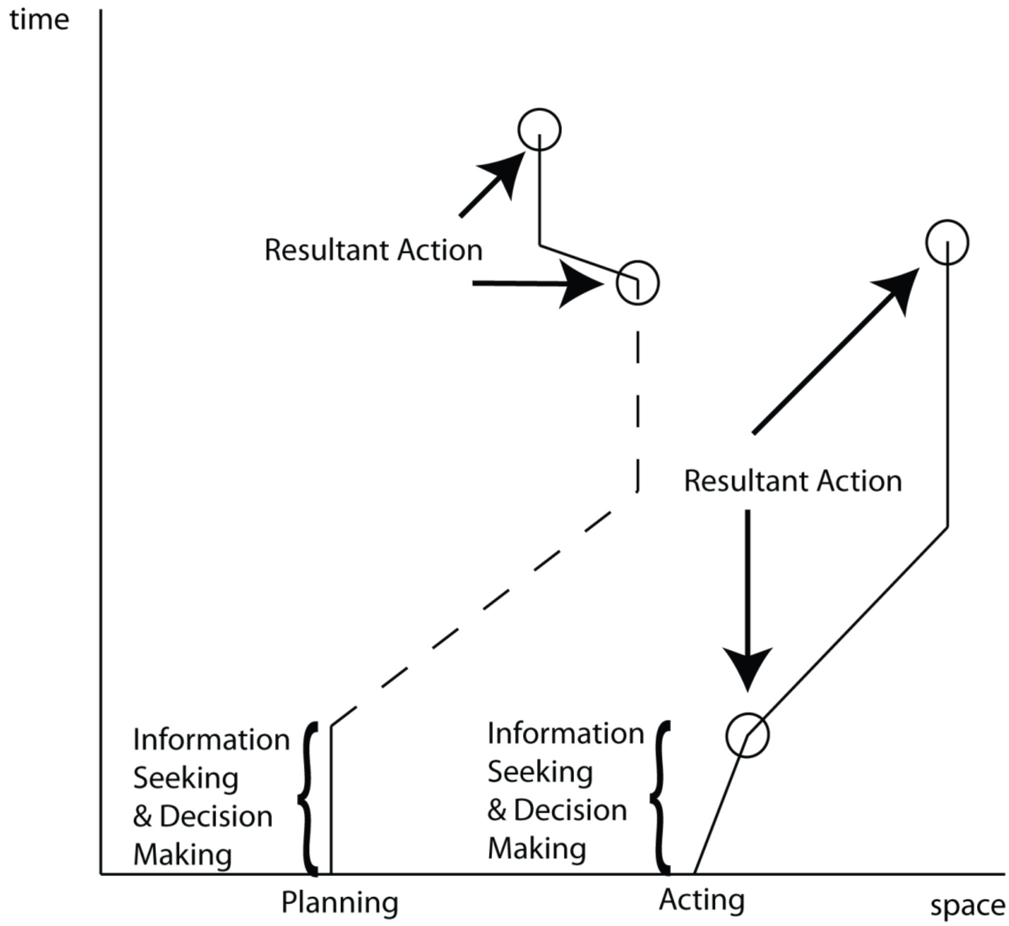


Figure 8 – Spatio-temporal difference between acting and planning

The acting phase will make use of the plan developed previously to guide the actions through space and time. However, due to the uncertainty of the contexts during the planning phase, it is likely that these plans will need to be amended to reflect unforeseen circumstances that occur during the acting phase.

In summary, the activity of a mobile person should include the planning necessary in order for the execution of activity to be properly supported. This fits with the main concept underlying activity theory of object orientedness. It is not just the physical movements through space that allow the achievement of a mobile person's object, but also the planning required in order for these movements to be properly coordinated and better directed. In essence both planning and acting are focused on the same goal, with the acting phase representing the externalisation of the internal cognitive processes that occur during the planning phase.

3.1.3 The spatio-temporal constraints of activities

Activity in the definition given in the beginning of this chapter does not describe a key characteristic of activity as described by time geographers. This characteristic is that they are constrained in space and time, and that these constraints affect the abilities of an individual to engage in certain activities. The basic concept of activity in this thesis is as a set of movements and actions performed over space and time, and therefore these constraints limit the total number of these SubActions to be included in an activity. This therefore results in the constraints being an important part of the context that should be perceived by the mobile information seeker.

3.1.4 A new working definition of activity

In light of the characteristics introduced in the preceding sub sections, I provide an amended version of the initial definition of activity as given by Reichenbacher (2004). The original definition requires an additional reference to the hierarchical nature of activity, the two-phase characteristic and the spatio-temporal constraints. I therefore define activity in the scope of this thesis as *"the planning and acting out of a motivated, hierarchically structured sequence of coherent actions carried out at specific locations for certain periods of time, and within the spatio-temporal constraints of the individual actors spatio-temporal environment"*. This extended definition can then be used to design interactions and visual representations that are sensitive to these characteristics of spatio-temporal activities, and therefore can help the mobile information seeker more effectively reach the goals at which their information seeking is directed.

3.2 Conceptualising the Cognitive Domain

External visual representations of geographic relevance are conceptualised as tools which can aid the cognitive processes of an individual involved in the task of seeking information, with a better representational scheme resulting in a better support of these cognitive processes. At a general level, cognition in this thesis is conceptualised from the symbolic viewpoint. This viewpoint is based around a metaphor, that the cognition of an individual is a form of computation (Lewis 1999). A symbolic mode of cognition makes use of a metaphor; that the mind operates like a computer and with the mind being a symbolic system and cognitive processes manipulating these symbols. This allows primitive computational processes of cognition to be defined in order to describe different aspects of human information processing. Evidence for the ability of this theoretical model to describe human cognition can be found by the development of computational models of cognition (cognitive architectures) that have been able to re-produce empirical results generated by human subjects, for example see (Lebiere et al. 2001). The cognitive domain in the framework described in section 3.4 encompasses the cognitive processes, categorisation and image schema, as all play a role in the use of visual representations.

Cognitive processes – Users of visual representations of geographic relevance will utilise these representations as a form of cognitive tool that can aid the cognitive processes involved in seeking relevant information. A cognitive process is defined here as the processing, storage or retrieval of information in the cognition of an individual, e.g. remembering information, and this definition is based around the work of Oulasvirta et al. (2005). These cognitive processes are then utilised in order to attain the goal of higher level cognitive tasks, such as information seeking or decision making. For example, filtering data, as discussed in Chapter 4, results in less information needing to be visually processed and therefore aids the visual attention of the user (Swienty et al. 2008a). Furthermore, the cognitive processes are strongly associated with the higher level cognitive tasks, such as decision making or information seeking, that must be carried out in order to choose a course of action. Again, the process of filtering data provides a good example of this, as not only will it support the low level visual cognition of the individual, but also result in fewer alternatives to compare and therefore a simpler decision.

Basic Domains and Image Schema – Common structures held within the cognitive processes of an individual allow the development of understanding and reasoning through the application of metaphorical thinking. In order to develop metaphors that intuitively communicate relevance, it is important to first describe the cognitive structure of relevance for an individual being communicated to. The cognitive structures within the framework are therefore represented by the concepts defined in image schema and basic domain theory. Metaphors can then be discovered which hold similar structures to these cognitive structures, and provide an intuitive mapping to relevance. The role of image schema in this thesis is therefore as a means to improve the visual and linguistic communication of geographic relevance.

Involving these three elements within the framework will provide a cognitive basis for the development of the visual representations. The process and tasks help inform the design of the visual representations and interactions so that they are efficient to use. The structures are focused on providing a clear communicating of the meaning of an interaction or visual representation, and therefore help the individual make more effective use of the visual representations of geographic relevance.

3.3 Conceptualising the Representation Domain

The review of literature demonstrated that the meaning of the term representation is inconsistent across different disciplines. In this thesis, we borrow from the elements from definitions of Zhang (1997), Raper et al. (2002) and Fairbairn et al. (2001) and define a representation of geographic relevance as being the geographic relevance of real world entities perceptibly expressed as modifiable visual symbols (e.g. maps, tables) with external rules, constraints, or relations embedded in their physical configurations (e.g. spatial relations between map objects). This definition attempts to capture the notion that these representations are both visual and interactive (*modifiable*), that the relationships within these visual representations play a role within their use and that the main aim of the representation is to allow all these components to be perceived by an individual user. The support of this perception is an important point, as this is the main purpose of the representations. Improving the ability of the information seeker to perceive what is relevant will enable them to make better choices about where, when and what to do and allow them to focus only on the most relevant information. Following this definition means that the process of building a representation of geographic relevance must therefore focus on defining the geographic information needed by an individual, deciding how to visualise the relevance criteria and how the representation can be interacted with.

Before this process can take place, it is necessary to first describe a conceptualisation of data output by the relevance assessment used as input to the design approach described in subsequent chapters. Only the relevance of point objects, such as points of interest, is considered in this thesis due to the constraint of time and data availability. The relevance assessments result in a dataset containing an XY coordinate for the spatial location, along with a value for each relevance dimension. Currently the relevance assessment outputs a geographic information object, with its relevance measured by the six criteria spatial proximity, topicality, spatio-temporal proximity, directionality, co-location and cluster (De Sabbata 2010). Also included is a value formed from a combination of these six criteria, this value is referred to as geographic relevance. These relevance dimensions consist of values expressed as a real number scaled to a range [0, 1]. On a conceptual level this range is a continuous one, with a variety of functions providing the mappings between absolute measurements of space or semantics and the range described above. Based on the description above, we can define the conceptual data model for the input data using the primitive of geographic information described as a geo-atom (Goodchild et al. 2007). From a relevance perspective, a geo-atom consists of a single measurement of a property at a spatio-temporal location and is formalised as $<x, R, r(v)>$, where x = spatio-temporal location, R = relevance criterion type and r(v) = value of that relevance criterion on a range [0, 1]. For relevance, the time of the measurement is the time that the query was launched by the mobile information seeker, which would initiate the relevance assessment and result in the measurements. This method then results in each relevance criterion being conceptualised as a single geo-atom. These geo-atoms can then be aggregated into a single geo-object, which result in one spatio-temporal location (x) being linked to the relevance criteria $\{R_1 \ldots R_n\}$ and their related values $\{r(v)_1 \ldots r(v)_n\}$.

This conceptual representation forms the basis for all subsequent analyses that occur in order to represent GR. It is clear that the relevance assessed data used as input to this process are best conceptualised as objects, rather than fields. However, this does not mean that the relevance criteria should remain as objects and the advantage of this conceptual approach is that it also allows the inclusion of analytical functions that can turn the geo-objects into geo-fields. An example of this would be the application of a kernel density function; this will be more fully explored in Chapter 5.

3.4 A conceptual framework for developing representations of Geographic Relevance

The conceptual framework for developing representations of geographic relevance in this thesis is formed from the three domains mentioned above. This approach is derived from the literature review in Chapter 2, which suggests that mobile information seeking takes place within a context and requires cognitive processes to be focused on an external representation in order for the individual's tasks to be solved. This framework can be seen below in Figure 9. The

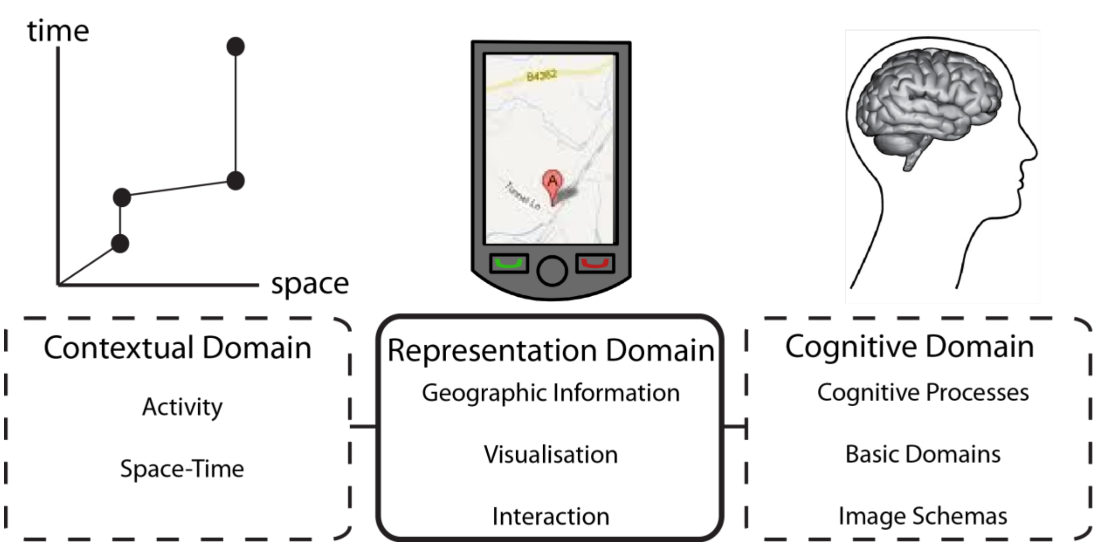


Figure 9 - Conceptual framework for developing representations of geographic relevance

conceptual framework links these domains together in order to produce representations that are designed according to the context of a mobile information seeker, and thereby supporting the cognitive processes. No direct interaction is assumed between the cognitive and contextual domains and so it is the representation that links both the context and cognition together, as it is used to solve the tasks in the given context demands whilst utilising the cognitive processes. This arrangement means that the representational domain is the focus of the approach, as would be expected in the scope of this thesis.

The conceptual framework below defines the general approach taken in this thesis and is therefore also used to influence the workflow discussed below for building a representation of GR as well as a blueprint for the structure of the remaining chapters of this thesis. This workflow is shown below in Figure 10, and begins with the relevance assessed data. The overall process then begins with irrelevant data being removed, following this task relevant information is added, and finally the data is enriched with metaphors. The structure of this workflow is such that the elements in the context and cognitive domains are analysed to inform the adaptations of the elements in the representational domain. The first adaptation operation, described in Chapter 4, is to filter the input dataset, based on an analysis of the spatio-temporal activity supporting the adaptation of the representational domain. This adaptation is the removal of geographic information objects that are not accessible to the mobile information seeker.

Chapter 5 then takes the filtered data as input and uses the cognitive domain to influence the adaptation of the representational elements. The representation domain in this chapter consists of elements that affect the perception of both entities (dimensionality, object/field, vagueness) and relations (frame of reference, explicitness of relationship), and will be adapted using from past research about the human processing of geographic information (Barkowsky 2002). Furthermore, it is acknowledged within the workflow that some properties can affect the perception of entities and relations, such as spatial scale. Thus, certain elements exist in both entities and relations. The elements can then be adapted to fit the geographic relevance criteria and the cognitive tasks that an information seeker will need to carry out in order to perceive these criteria. In Chapter 6 the cognitive domain is also a subject of analysis. Categorisation procedures aim to support cognitive processes engaged in the information seeking, by allowing the individual to rapidly narrow down a search to the most relevant objects. Additionally, the application of cognitive theories of basic domains and image schema aim to create meaningful linguistic, visual and interactive metaphors of geographic relevance. After context and cognitive adaptations described in the workflow have been carried out, an interactive, visual representation of geographic relevance exists that fits to the original definition of an external

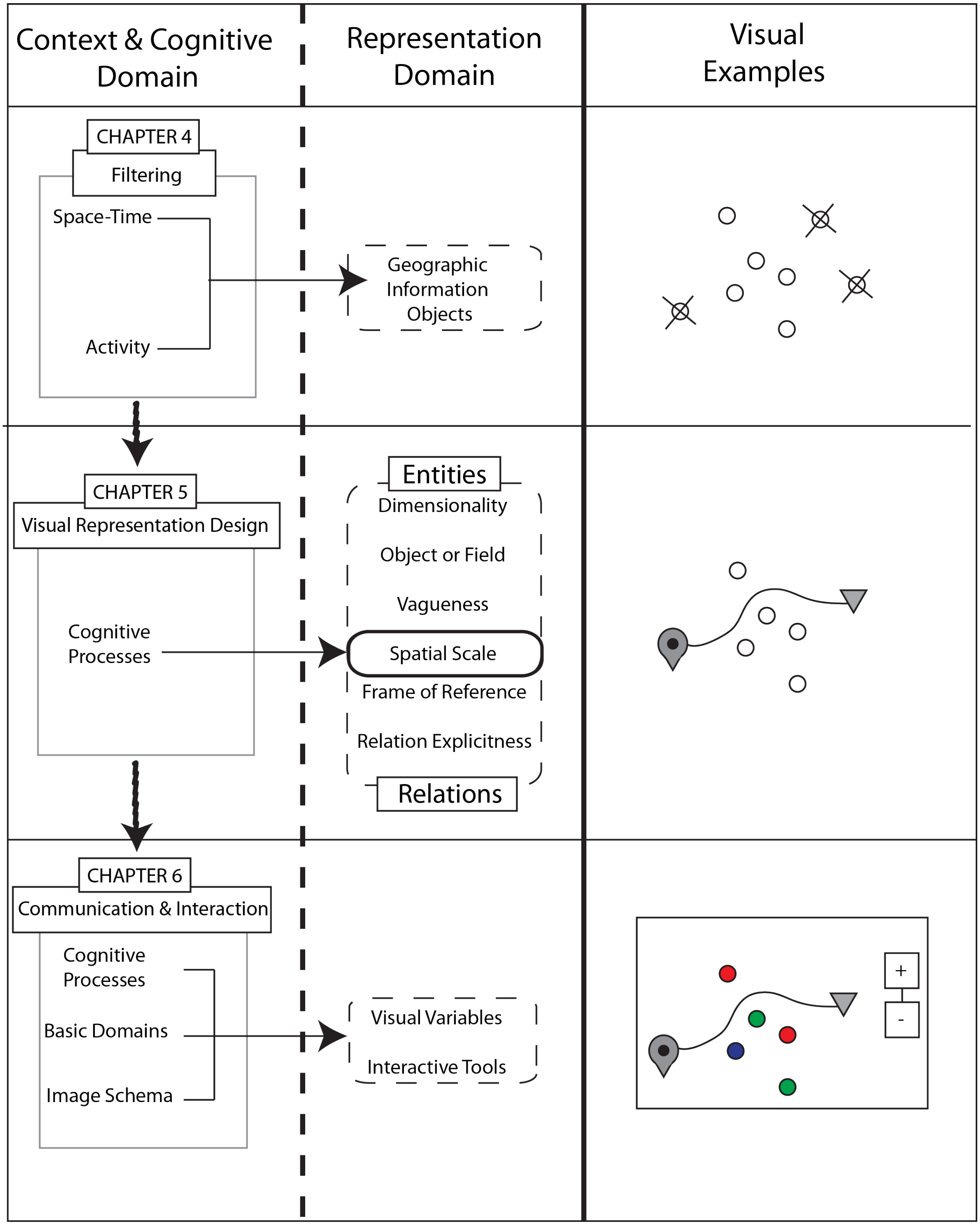


Figure 10 - Conceptual workflow for building interactive representations

representation of geographic relevance as described above in section 3.3. Finally, evaluations will be carried out seek to determine if there is evidence for the methodology chosen being valid one, as well as the generation of knowledge of how cartographic design influences the information seeking processes of individuals. This will be discussed further in Chapter 7.

Chapter 4 Filtering Relevance Datasets to Support Spatio-Temporal Activity

This chapter represents the first step in the process of visual representation; the removal of irrelevant information. Specifically, it describes a method that utilises the context of spatio-temporal activity and develops analytical procedures that can be designed in order for the relevance assessed datasets to be filtered automatically for information seekers in the planning and acting phases of activities. Geographic relevance assessments of points of interest (POI) result in datasets with each feature possessing values for several relevance criteria, an example of such a dataset is shown in Figure 11. Such datasets may hold a large number of features (2279 in the example on Figure 11), which results in the need to remove those objects that can be thought of as irrelevant or only of little relevance to the individual mobile information seeker. These superfluous data can then be removed from the representational process, i.e. the dataset can be filtered based on the geographic relevance. The concept of relevance is strongly linked to the spatio-temporal proximity of a real world place, as this relevance criterion is a measure of the ability to access an object or place, if it is not accessible to an individual then it is unable to provide any (immediate) utility to them. This has been clearly shown by conceptual and empirical work that has found the relevance criterion of spatio-temporal proximity to play a fundamental role in the judgement of relevance (De Sabbata and Reichenbacher 2012, Brimicombe and Li 2006).

The definition of activity given in section 3.1.4 is used to develop a model of spatio-temporal activity, and analytical procedures that offer a novel means to filter data. This model is based on the ideas of time geography, and specifically the quantitative approach defined in (Miller 2005). This allows a system to represent the spatio-temporal constraints of the individual explicitly. Hence, an inaccessible place or entity can no longer become part of the information seeking or decision making process. The model developed results in data being filtered in order for an individual to create a plan that can include different types of activities at various places and times, whilst also incorporating the spatio-temporal constraints of the activity plan. Furthermore, when the plan is being acted out, it is possible that unforeseen circumstances result in the individual needing to seek information to alter the plan. The information can then be filtered using the spatio-temporal constraints held within the existing plan, with the amendments then upholding the original constraints expressed during the planning phase.

Some content in sections 4.3 to 4.6 was originally explored in (Crease and Reichenbacher 2013) and (Crease 2012).

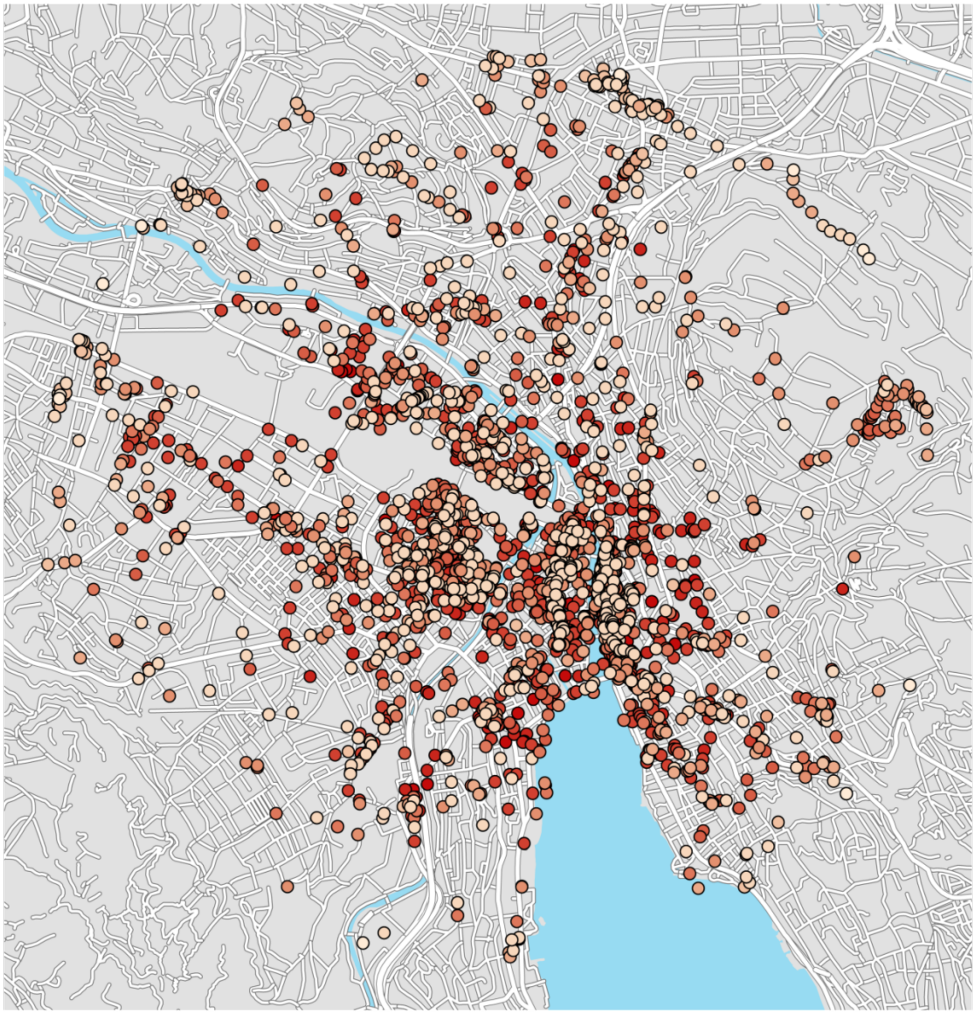


Figure 11 – Unfiltered relevance assessed POI dataset in Zürich, with geographic relevance for each POI encoded as colour value (darker red = more relevant).

4.1 Data Preparation

For the analysis described below, data representing the points of interest and a street network was required. Street network data for Switzerland was downloaded from GeoFabrik.de as shapefiles, clipped to the Zürich region and then topologically cleaned using ESRI Network Analyst tools. The points of interest dataset utilised was provided by the GeoRel project, and contained relevance values for five criteria (spatio-temporal proximity, cluster, co-location, directionality, topicality) and one value of relevance that represented a combination of these five criteria. This dataset contained a total of 2279 objects located in the city of Zürich, Switzerland. These were then split into the following separate datasets using the sub-category field:

- Toyshops (6 places in total)
- Bookshops (16 places in total)
- Restaurants (496 places in total)
- Fast-food restaurants (54 places in total)
- Museums (19 places in total)

The analysis was then carried out by linking each one of these datasets to a SubAction type, which are defined below in the scenario described in section 4.4.1. These represent the result sets that will then be filtered in order to support the creation of a spatio-temporal plan of action, and also during the amendment of the plan.

4.2 Filtering the Data

Several approaches to filtering geographic relevance assessed datasets are possible. Commonly the filtering is carried out through the specification of hard boundaries for category type and spatial distance, e.g. all restaurants within 500m. However, as explained by Reichenbacher (2009b), this approach can result in some relevant places being removed from the result set, and some irrelevant places being included. This chapter therefore focuses on the development of an approach that gives a more accurate representation of what is relevant and what is irrelevant.

A basic division between possible approaches can be drawn between those that are adaptive and those that are adaptable (Fischer 1983). The difference between these two approaches is explained by Reichenbacher (2003) - adaptive methods automatically alter a systems behavior, e.g. filtering data using some contextual analysis of the mobile information seekers situation to inform this process. Adaptable methods allow the individual to control the systems behavior through manual interaction, such as manually setting the properties of an application or query. A possible adaptable approach for relevance data might be to develop an interface consisting of slider bars, with each bar allowing the filtering of data along one relevance criterion. However, such an approach requires numerous interactions to be carried out before a desired subset of results can be found. The approach taken in this chapter is therefore suggested by Mountain (2007) as being most applicable to mobile information seekers, which is to limit the interaction required by the filtering process and make the filtering an adaptive process.

The filtering approach taken here takes place in two stages, and aims to define which geographic information objects should be made available to a mobile information seeker, and how many should be visually presented to the information seeker. The approach borrows from search engine filtering methods, which defines a result set and then presents a 'chunk' of this information to the user on a result page. The individual can then navigate through the result set moving from one result page to next result page. Oulasvirta et al (2009b) differentiate between three different sets when describing results, and all three play a role in the approach described in this chapter. These three sets are described below, and a visual example of this description is shown in Figure 12 :

Result Set – This set contains all the items that are returned by a query, analogous to the total amount of 'hits'. For geographic relevance this would incorporate all the objects assessed by the relevance assessment process. The approach described below uses the datasets described in section 4.1 as example result sets located within the city of Zurich.

Presentation Set – All the objects in the result set that are viewable by the information seeker are considered part of the presentation set. For traditional search engines the result set and the presentation set are often the same, but in the context of geographic information seeking this may not be desirable. The reason this would be inappropriate is because some of these objects may be spatio-temporally inaccessible to the information seeker. These inaccessible objects should therefore not become part of the presentation set as they can provide no utility if they cannot be physically reached. The move from result set to presentation set therefore requires filtering to take place, and the approach taken here is to filter out objects according to the spatio-temporal constraints of the information seeker's activity, to allow the result set to only contain places which are accessible to the mobile information seeker given these constraints.

Page Set – As the presentation set could contain a billion or more web documents, the amount of information that is actually displayed to the information seeker must be limited. This limitation is approached by ranking the presentation set based on relevance and then partitioning it into chunks, and presenting these chunks one at a time, starting with the chunk containing the most relevant objects, in the form of results pages. The results that are visually presented to the user are defined as belonging to the page set. This method represents a filtering process, as only a small number of the web documents end up being actually visually perceived during the information seeking process. This supports the cognition of the individual, as too many results end up harming the information seeking and decision making process of the individual, which performs best when only small sets of objects must be compared (Johnson and Payne 1985). The default size of this page set is 10 for the majority of popular search engines (Ozcan et al. 2011). To apply this to geographic relevance, the approach below utilises the context of the activity, specifically within the two phases defined in Chapter 3 of acting and planning, to define how many objects from the presentation set should actually be visually presented to the user at any one time.

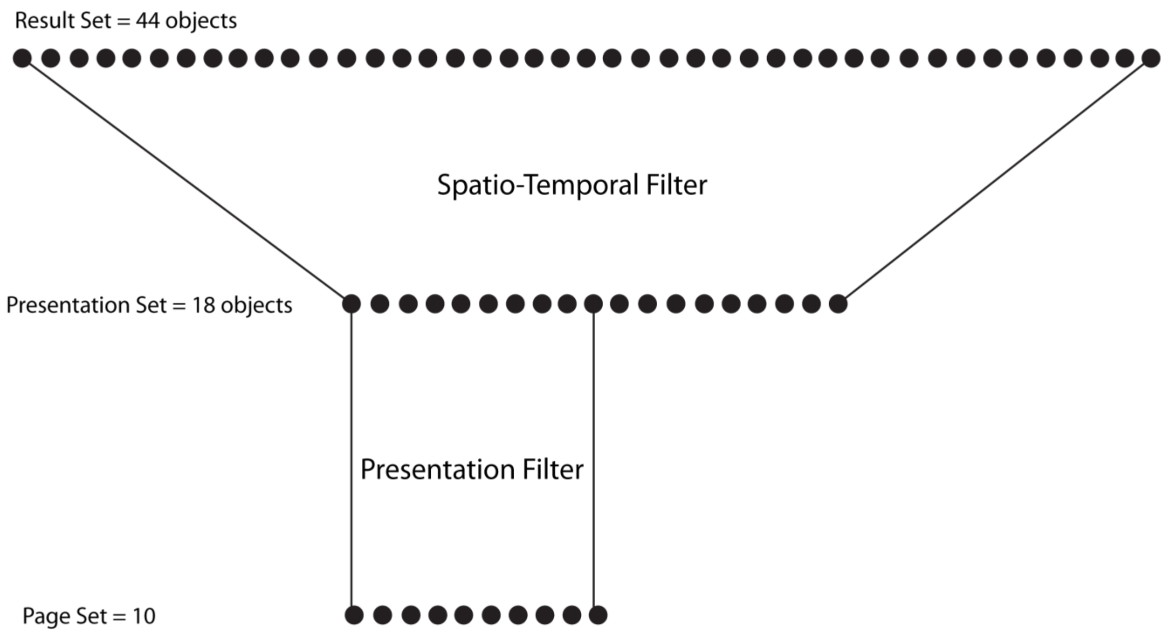


Figure 12 – visual example of the filtering process

In summary, the basis for the filtering is the definition of activity given in Chapter 3, and the approach described in this chapter therefore considers the spatio-temporal and activity context of the user to inform the move from result set to page set. I first describe filtering of the result set with the application of model of the spatio-temporal constraints (section 4.3) that allows spatio-temporal accessibility analysis to be carried out and inaccessible objects removed. This is applied to the dataset above to demonstrate how the presentation sets are derived from the result sets, and the number of objects that result from its application. The demonstration incorporates both the application of the filtering process during the formation of a plan (section 4.4) that fits to the spatio-temporal constraints to activity. Also, as activity plans will need to be amended as the plan is acted out, it is demonstrated how these filters can also be applied during these acting phases to support plan amendments (section 4.5). Finally, a description of how the size of the page set should be amended for both acting and planning contexts of an activity is described in section 4.6.

4.3 A Model of Space-Time Constraints and Preferences for Filtering

This section explains the structure of the proposed model and the analyses that can be carried out in order to assess spatio-temporal accessibility. The methodology proposed is based around research carried out by (Kwan and Hong 1998) and (Raubal et al. 2004), which looked at representing the restrictions on possible choice sets through analysis of the spatio-temporal constraints of an individual. However, the model deviates from these methodologies in two main ways, through its explicit incorporation of activity theory, and its ability to adapt to unforeseen changes in an individual's spatio-temporal context.

The eventual aim of this process will be to remove objects that are no longer accessible in order to support the planner in the creation of space-time projects that are properly constrained in space-time and fit the preferences of the information seeker. The first step in the analysis is to identify the constraints; the analysis can then operate on this model of constraints and calculate what is accessible based on the constraint model. These constraints represent start and end times for the whole activity and the fixed actions which must take place between these start and end times. The model defined here has three levels within its hierarchy of activity, action and sub-action. The lowest level of activity theory that deals with sub-conscious operations, such as opening doors or climbing steps, is not included as this level of detail is considered unnecessary for spatio-temporal analyses. The analyses focus on movements across space, and movement is in this model understood to be a conscious act. Additionally, geographic data input into the model does not include suitably detailed data such that the location of doors or steps can be included, and therefore it is not possible to predict where such detailed actions would be necessary. The model therefore contains two levels of actions, the lowest level consisting of *SubActions* which are constituents of a higher level consisting of *Actions*. Breaking down the action level of activity into two levels is something that is not considered in the original Activity Theory, but practical implementations often take this approach, e.g. Yu and Cai (2010). With this in mind, the atomic unit of activity in the model is therefore *SubAction*, which is defined in equation 1 where CP is a set of spatio-temporal constraints and spatio-temporal preferences that relate to that *SubAction*. These sub-actions represent the two types of spatio-temporal behaviour defined by Time Geographers, this is travelling to a location in order to carry out an activity (travel time) and the time taken to carry out the action at that location (stay time). The next level in the hierarchy is *Action*, which is formed from one or more *SubActions* which are directed towards the same goal e.g. buying a book, drinking a coffee. The highest level of *Activity* is formed from the *Actions*, along with spatio-temporal constraints of its own, which reflect the spatio-temporal domain within which an *Activity* takes place, represented by the start time and the planned duration.

Constraints attached to each *SubAction*, *Action* or *Activity* within the model can be spatial, temporal, spatio-temporal, and also inter-action. Attaching a spatial constraint to one of these components results in the analysis only concentrating on those objects within a fixed spatial boundary. A good example for this constraint type are public transport zones, where particular tickets allow access to only certain zones. These spatial constraints can also be expressed as an amount of time and a coordinate, with the potential path area derived from these values used as the spatial boundary. Spatial analyses can then be carried out in order to determine the accessibility of objects, the most common being the calculation of topological spatial relationships, such as contains or overlap, between potential objects and the boundaries of these spatial constraints, as defined in (Egenhofer and Franzosa 1991). The current model only operates on point data, and therefore the most important relationship to derive is that of containment. This allows the system to discover which objects are within the spatial constraint. A temporal constraint is made up of two separate times (start and end times) or a relative time or duration (2 hours). These constraints therefore can be used to represent components of the hierarchy with no spatial fixity. These constraints can allow a user to determine a time at which they would like to participate in a potential activity but allow the actual location to be flexible. The temporal fixity can also be varied for these constraints by specifying an earliest time and latest time for the start or end constraints, e.g. start hiking by earliest 08:30 but before 10:00. This allows some flexibility to be incorporated into the model and is more applicable for the expression of preferences of a user. Simple before, after or during comparisons between times can then be carried out to determine if an object is accessible. This location can then be fixed during the plan building process, an example is the Eating action in the scenario below in section 4.4.1. Additionally, these constraints can allow the information seeker to define how long they want to carry out an action, for example finding hiking trails that require a shorter train trip than 1.5 hours.

Spatio-temporal constraints are a mixture of both spatial and temporal constraints although some differences exist. The *location* parameter can refer to punctual or areal geometrical objects, with the constraints to movement only being significant over a certain period of time. The spatial fixity can be relaxed by allowing more than one location to be added to the constraint. For example, if an individual must visit a post office before a certain time to make a payment they are able to visit any post office, and therefore the degree of spatial fixity is somewhat relaxed when more than one post office is available to them in their spatio-temporal domain. Inter-action constraints are included in this model because research has shown that the time it takes to perform an action (stay time) at a location is reflected in the amount of time the individual will travel to perform that action (Dijst and Vidakovic 2000). A good example would be a hiking activity, where few hikers would be happy travelling 5 hours to and from a trail that takes only one hour to hike. Therefore, the inter-action constraint is specified as a ratio and can be used to compare a *SubAction/Action* with another *SubAction/Action* and find objects for which this ratio does not meet the individual's preferences.

To summarise, the model is formed as a hierarchical structure of various constraint types that describe an activity. The goal of the planning process is to fix flexible elements of a constrained action, such as where something takes place in the case of a temporal constraint, and also to fix actions which are flexible in both space and time. To support the formation of these plans, the spatio-temporal accessibility of potential locations for the desired action must be assessed to predict if they can be included in the plan, and allowed to become part of the user's choice set. This requires analysis to be carried out on the model, and will be explained in the following section.

4.3.1 Spatio-Temporal Analyses of the Model

The aim of the analysis is to find objects that are not accessible based on the constraints and preferences specified by the planner. This analysis is carried out on network datasets that represent a street network and can provide estimations of travel time, based on speed and distance values contained in each edge of the network. The basic unit of analysis is assessment of travel time between two locations and is calculated using Equation 1 below:

$$travel(a+b) = \frac{d^{ab}}{v} \quad (1)$$

Where d^{ab} is the total network distance when travelling from current location a to destination b and v is velocity of travel. The total activity time of travelling to a location and then carrying out the activity is then calculated with Equation 2:

$$(a, b, s) = travel(a, b) + \ {}^{s}duration \quad (2)$$

Where s is total duration of stay time at location b. As the locations for the actions are chosen, the current time is re-calculated at which the action would finish at the location last chosen. This is shown in Equation 3, 4 and 5 below:

$$B = \{b_1 \ldots b_n\} \quad (3)$$

$$S = \{s_1 \ldots s_n\} \quad (4)$$

$$current(\mathrm{B}, \mathrm{S}) = start^t + actT(start^{xy}, b_1, s_1) + \sum_{i=2}^{n} actT(b_{i-1} b_i s_i) \tag{5}$$

Where Equations 3 and 4 are the ordered sets of action locations (B) and their associated durations (S), $start^t$ $start^t$ is the planned start time of the activity, $start^{xy}$ is the planned start location and n is the number of locations so far included within the space-time project. After these calculations Location k is only accessible if the following constraints hold in Equation 6:

$$current(\mathrm{B}, \mathrm{S}) = actT(a, b, s) \leq start^t + \ pduration \ \ \textbf{AND} \ k^{ot} \leq actT(a, b, s) \leq k^{ct} \tag{6}$$

Where k^{ot} and k^{ct} are the opening and closing times of location K and *pduration* is the planned duration available before the next constraint. A well understood characteristic of spatio-temporal activity is the degree of fixity of spatial and temporal constraints (Kwan, 2000). As some information seeking relates to a fixed spatial location where the action must end, accessibility can also be calculated with a fixed-end destination (Equation 7).

$$current(\mathrm{B}, \mathrm{S}) + actT(a, b, s) + \ travel(b, c) \leq start^t + \ pduration \ \ \textbf{AND} \ b^{ot} \leq actT(a, b, s) \leq b^{ct} \tag{7}$$

Where c is the fixed-end destination, b^{ot} is the opening time of location b and b^{ct} is the closing time of location b. Essentially this analysis calculates the difference between the time available and the time required to carry out an action at a location which can then be used to infer whether the location is accessible or not.

4.4 Filtering for Acting and Planning Phases

During the planning phase data is filtered based on the constraint model specified above. Spatio-temporal analyses on this model initially discover what is accessible and what is not inaccessible. Data that relates to locations that are inaccessible are then filtered. The first step is to define the input data. This input takes the form of a hierarchical structure of fixed spatio-temporal actions, and the planning process then fits the flexible actions around these fixed actions. This process results in filtering data by removing features that are not accessible within the calculated time budget. As each choice is made, the time budget shrinks and therefore more POI features become inaccessible and are then removed by the filtering process. These iterations gradually shrink the presentation set, and finish when the next constraint is reached or no more points of interest are accessible. This process is shown graphically in Figure 13 below. The acting approach utilises the same approach, but with the spatio-temporal analysis acting on the planned activity model defined during the plan phase. Filtering in the acting instance is aimed at supporting changes to the plan, such as adding or modifying SubActions and Actions. This means discovering objects in the result set that still meet the constraints imposed by the original plan, and can therefore be included in the amended plan. The first step is to define a scenario that can be used as input to the planning phase, and used to define constraints that allow the accessibility to be calculated and the data to be filtered. This planning process creates an itinerary, which can then be amended during the acting phase as unforeseen circumstances require. These amendments require further choices by the information seeker, and these choices are supported by filtering places that are not accessible based on analysis of the constraints of the original plans itinerary.

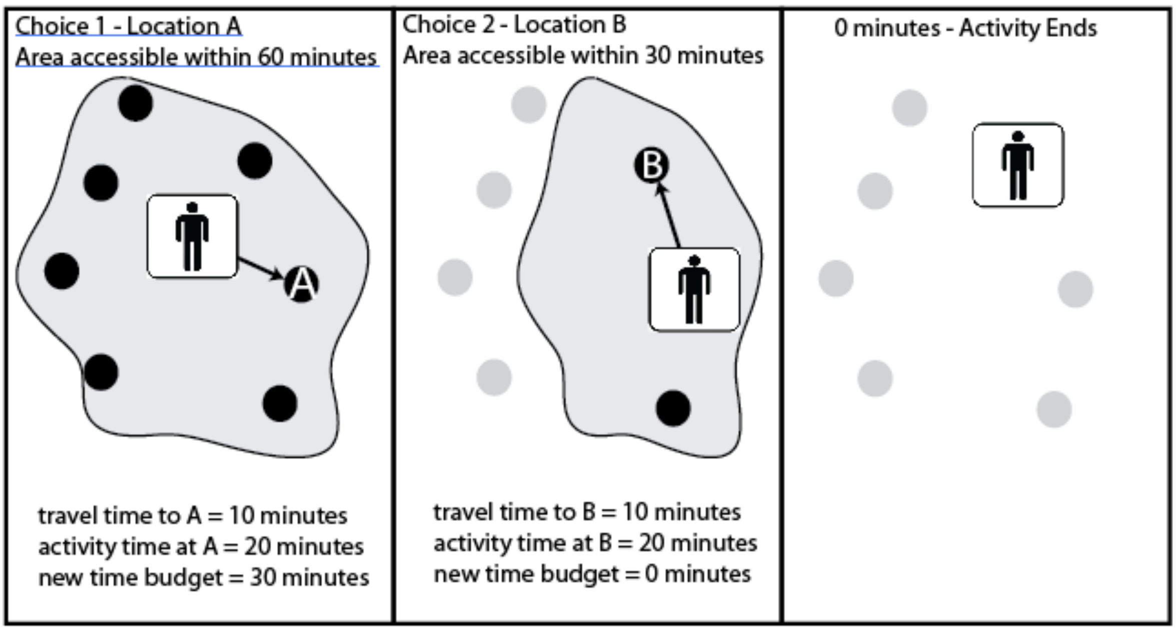


Figure 13 - A schematic diagram showing the progressive filtering of the points of interest

4.4.1 Defining a Scenario

The analyses described above must operate on some input data in the form of spatio-temporal constraints, and this input data is provided in the form of a hypothetical scenario. This scenario will be referred to throughout the remainder of the chapter in order to demonstrate how the plan building process is achieved by the previously described analyses. The scenario is as follows:

Frank is travelling from Bern and arriving in Zurich at 9am and is staying until 6pm to attend a short business meeting, this meeting is from 10 to 11.30 am at the UBS head office. He prefers that every action he plans between arriving and the meeting start was at least 15 minutes tram ride from the UBS office to prevent too much travelling. After the meeting he has only personal commitments that he needs to fulfil. The first is to start eating between 11.45 and 12:30pm for an hour and spend no more than 15 minutes for the travel time; the second is to watch a film that is showing at three cinemas in Zurich at the same *time, 3.15pm until 5.30pm. He can travel by foot or public transport within the city of Zurich, although if possible he would prefer to walk. Very important is that he always remains at least 15 minutes by tram from the main train station in case of a work emergency that would mean travelling back to Bern. Additionally, Frank wants to plan some flexible actions, he would like to visit a toy shop and a book shop to buy a present and visit a museum for an hour.*

This results in a hierarchical spatio-temporal constraint model as shown below in Figure 14.

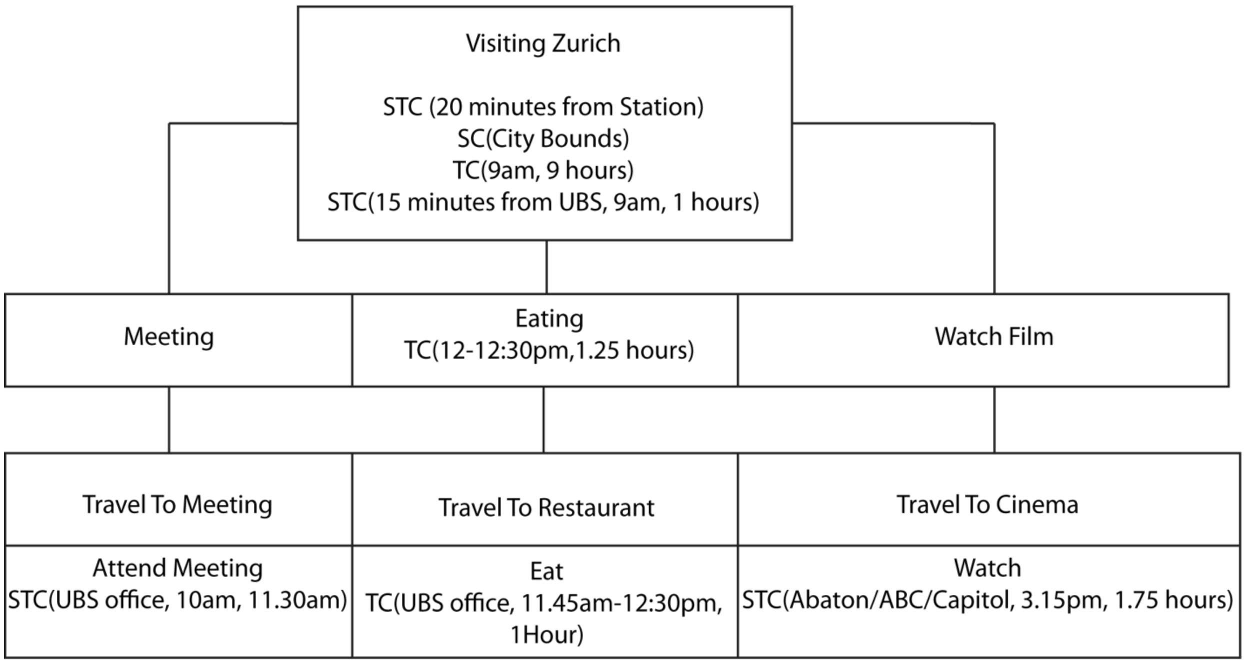


Figure 14 - Hierarchy view of constraints (SC=Spatial Constraint TC=Temporal Constraint STC=SpatioTemporal Constraint)

The hierarchical nature of the activity is clear with Meeting, Eating and Watch Film actions being the constituent parts of the activity as a whole. Moving to the temporal perspective is achieved by ordering these sub actions into a chronological order, moving to a spatial view can be carried out by taking the location parameters for each *SubAction*. The spatio-temporal perspective is carried out by taking both the spatial and temporal parameters for each *SubAction* and ordering them chronologically. Along with these fixed *SubActions* that must take place, there are considerable amounts of spare time. Frank can then fill this spare time with some flexible activities that he would like to carry out during his trip to Zürich. Currently Frank has an hour to fill before his meeting, half an hour after his meeting, 1 and three quarter hours after his meal and half an hour after his film. The plan building process therefore focuses on these flexible actions and fits them into these time gaps available to him.

4.4.2 Generating the Plan

Now that the scenario data has been added to produce the constraint model, it is also necessary to define the flexible actions and *SubActions* that also need to be performed. These flexible actions are deciding where to eat, where to watch a film from the three possible locations, when and where to shop for toys and books and when and where to visit a museum. Currently the analysis requires the flexible actions that need to be performed to be arranged in the order in which they should be carried out, the types of location relevant to the action and the number of locations that should be ideally visited during the planned activity. The inputs for these flexible actions take the form of an ActionType, the number of locations and the time needed at the location to perform the action. These are shown below and arranged in the order of execution:

Shopping	→	1 - Toy Shops	2 locations	10 minutes
Shopping	→	2 - Book Shops	1 locations	10 minutes
Eating	→	3 - Restaurant	1 locations	60 minutes
Museum Tour	→	4 - Museums	as many as possible	60 minutes

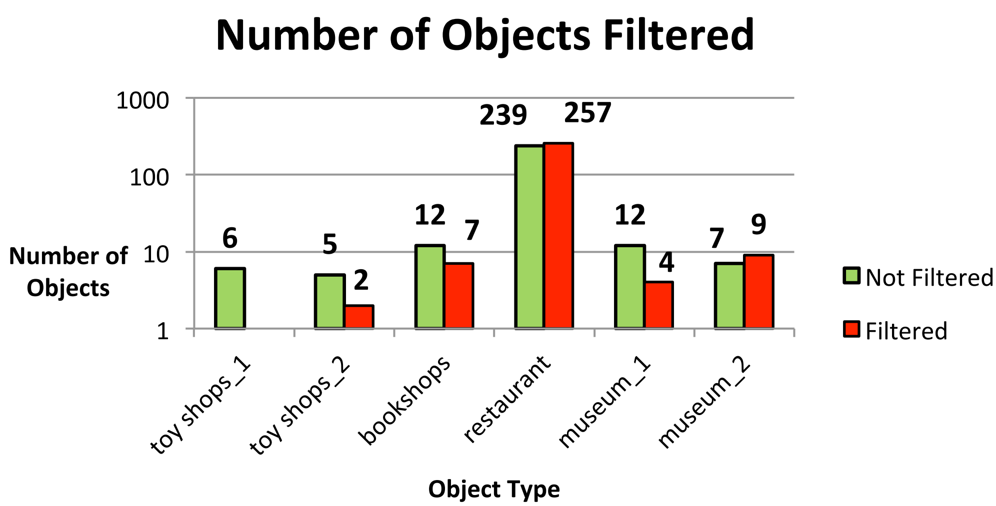
For the analysis, a walking speed of 5kmh was assumed, based on the findings of (Knoblauch et al. 1996). These data are then input to the model and the model is run. The processing takes place in an iterative fashion and the exact approach is described below in pseudo code. We simulate the choices of the user by picking automatically the object that is closest in travel time to the current location, although in a real system the choice process would mostly be guided by the information seeking of the user and the geographic relevance of each POI or also through the implementation of multi-criteria decision making tools (Bäumer et al. 2007, De Sabbata and Reichenbacher 2010). Although this represents a simplification to the real information seeking process, the aim of this chapter is to explain the iterative nature of the analysis and gradual filtering rather than the specific interaction (see Crease (2012), for more information on how these interactions could be supported). The steps necessary to create a plan are defined below

1. Get start location and start time
2. Check if a temporal constraint applies to the current time (e.g. Eating 11.45-12:30)
3. **IF** step 2 = true **THEN** Get the POIs related to the action (e.g. Restaurants)
4. **IF** step 2 = false **THEN** get the POIs related to the next flexible action
5. Get the POIs related to the action and the start location and start time

6. Get the number of locations N required for that action
7. Filter out any POIs that are outside the spatial domain constraint (15 minutes from main station)
8. Calculate the time budget (tB) (difference between current time and next time constraint)
9. Calculate total time for action (tact = travel time to each poi + stay time+ travel time from each poi to the next fixed destination.)
10. Remove any POIs where tact > tB.
11. Choose the closest POI p.
12. Add time taken to travel to p and the stay time to the current time and set the start location to p.
13. **IF** N<1 then go back and repeat from step 2 until N is reached OR number of accessible POIs == 0

During this process a plan is created, and during the creation of this plan the data is filtered for each stage in the planning. The results of this filtering process are shown in Figure 15 for each object type. The first stage of the planning process features little filtering, as the time budget is still relatively large, but as the process goes on more objects begin to be filtered as the time budget shrinks with each choice made, this can be seen for both the shopping action (toyshops and bookshops) and for the museum tour after lunch. This is process is displayed on a map in Figure 15 for the planning of the museum visit action, which takes place after lunch and before the cinema visit. Red crossed out points represent those museums filtered from the original dataset since they are outside the preferred spatial region (15 minutes tram ride form the main station) or those too far to travel to, visit and reach a cinema from afterwards within the time constraint allowed (roughly 105 minutes). Once the first museum has been added to the plan from a choice of twelve accessible museums, the time it takes to travel to and tour this museum is removed from the time budget. This results in the ability to access only 7 museums before the next constraint begins of watching a film at the cinema. After one of these seven museums has been chosen then no more time remains to be able to visit a third museum, and the planning process ends.

This progressive filtering of points not only removes irrelevant data, but also allows the individual to build a plan which adheres to the constraints dictated by the fixed actions that make up their chosen activity. Therefore a second output of the model is a list of locations with a time to start travelling, an arrival time, and an end time. This can therefore be used as an



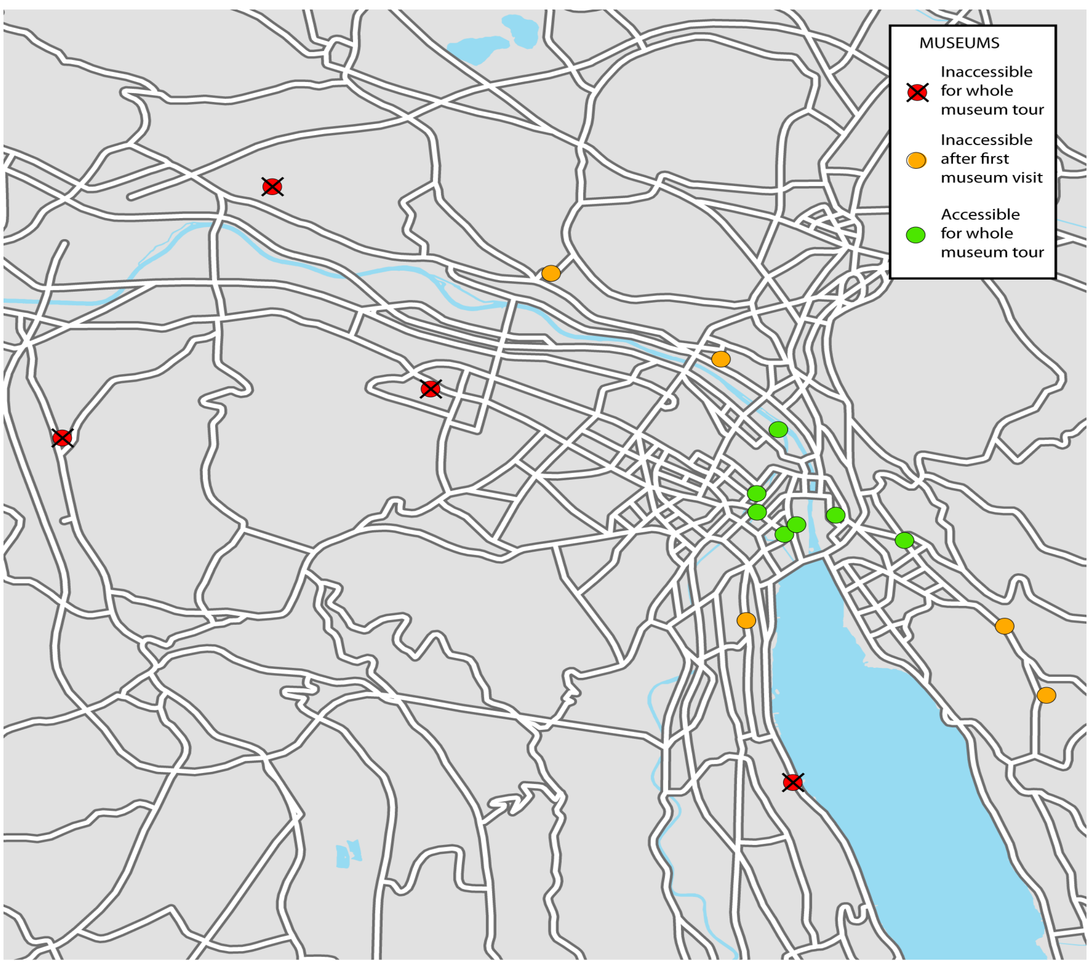
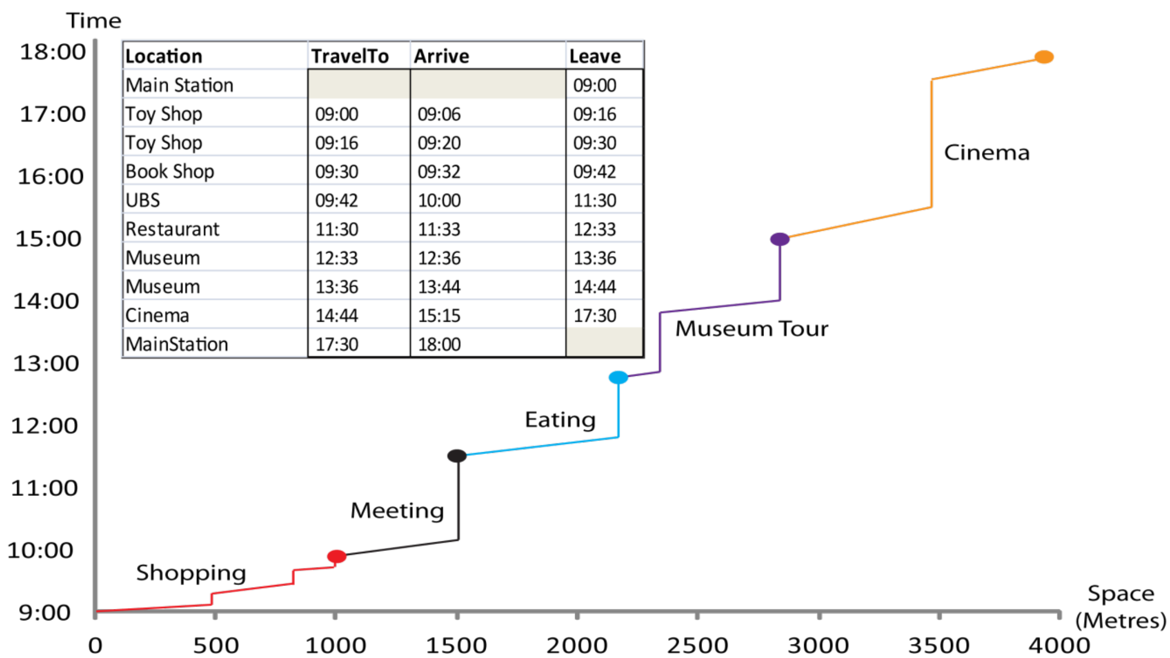


Figure 15 - Graph showing the filtering for all stages of the planning, and a map demonstrating progressive filtering of museums as the museum tour plan is built

itinerary which represents a set of plans about when and where each action should take place; this itinerary is shown below in Figure 16 along with the space-time graph and space-time path. This main use of this itinerary would be during the acting phase, allowing users to orient themselves and time their actions according to this time schedule. This could be represented as calendar entries or as a route overlain on a map display. One benefit of this is extra information available to the user during the acting phase. A second benefit is the ability to remove information during the information seeking that occurs within the acting phase. This filtering of information is again carried out by further spatio-temporal analyses that can remove POI features that are inaccessible based on the Actions and SubActions contained within the plan. These information seeking needs most probably rise due to unforeseen circumstances that require the plan to be amended, such as a late train or an unexpectedly closed restaurant. The next section looks in detail at how these needs can be supported by further analyses that can adapt the plan based on this need to amend the plan.



Location	TravelTo	Arrive	Leave
Main Station			09:00
Toy Shop	09:00	09:06	09:16
Toy Shop	09:16	09:20	09:30
Book Shop	09:30	09:32	09:42
UBS	09:42	10:00	11:30
Restaurant	11:30	11:33	12:33
Museum	12:33	12:36	13:36
Museum	13:36	13:44	14:44
Cinema	14:44	15:15	17:30
MainStation	17:30	18:00	

Figure 16 - Space-time Diagram output for the planned scenario

4.5 Filtering During the Acting Phase

During the acting phase plans must occasionally be amended to compensate for unforeseen circumstances. The list below represents a list of plausible amendments and how they affect the Actions and SubActions contained within the plan. The list contains a total of nine possible amendments:

Addition – add sub action to action or action to activity

Removal – remove sub action to action or action to activity

Lengthen – allocate more time than planned to action or sub-action

Shorten – allocate less time than planned to action or sub-action

Constrain – assign a constraint to a flexible action or sub-action

Relax – relax a constraint associated with a fixed action or sub-action

Re-Locate – the action or sub-action takes place somewhere other than planned

Re-Schedule - the action or sub-action takes place at a different time than planned time

Reorder – alter the order of actions or sub-actions

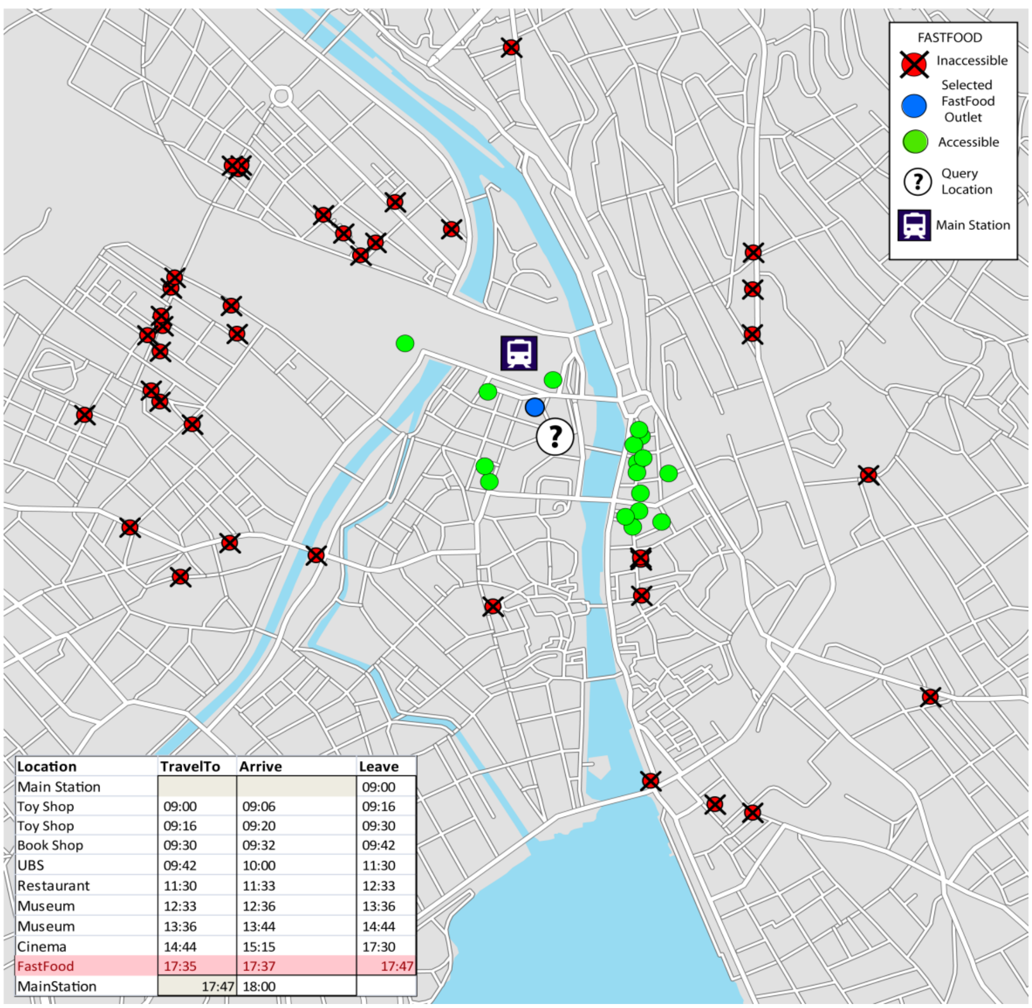
These amendments can be subjected to either the temporal, i.e. shorten, lengthen, or spatial (re-locate) values of an action or *SubAction*. However, the actual need to amend will be related to the context of the individual and will most likely result in more than a single member of the list above having to be employed with the overall change being most probably spatio-temporal. Additionally, certain members, such as remove or shorten could result in gaps that an individual might want to fill and therefore would lead to further information seeking in order to fill these gaps. It will not be the goal to explore all the possible amendments but to select some common amendments and show how these can be implemented into the analysis to allow as a means to filter the presentation set. The amendments focused on and described below are therefore the addition, re-locating and lengthening of *SubActions*, as these allow a demonstration of the resultant filtering processes. These amendments are first described within short scenarios before the results of the analysis are shown end explained. The process to include these amendments is to first run the model to generate the itinerary (shown in Figure 16) before using the itinerary data as input to this amendment process. The addition amendment takes this itinerary and fits an extra action into the resulting itinerary, filtering the data which represents locations that are outside of the constraints specified by the itinerary. The re-location first removes a planned SubAction, before adding one at a different location. The lengthen alteration takes a specified SubAction and lengthens it, this then shortens the time budget, and results in fewer places being accessible.

4.5.1 Simple addition scenario

Two separate scenarios are presented below that represent the need for the plan generated in Section 3 to be amended. The first scenario shown below represents the need to add a SubAction to the plan:

After the film is finished Frank finds himself outside the ABC cinema and hungry, the time is 5:35pm, his train is at 6:00pm. He therefore queries an application on his mobile system to find a Fastfood outlet. He therefore queries his application and brings and queries his mobile system. - Amendment = Add{FastFood}

This is perhaps the simplest scenario as it requires no complex re-organisation of the plan as the information need relates to a point in time where no other SubActions are occurring. The itinerary that is output after the amendment is displayed in Figure 17 below.



Location	TravelTo	Arrive	Leave
Main Station			09:00
Toy Shop	09:00	09:06	09:16
Toy Shop	09:16	09:20	09:30
Book Shop	09:30	09:32	09:42
UBS	09:42	10:00	11:30
Restaurant	11:30	11:33	12:33
Museum	12:33	12:36	13:36
Museum	13:36	13:44	14:44
Cinema	14:44	15:15	17:30
FastFood	17:35	17:37	17:47
MainStation	17:47	18:00	

Figure 17- Map showing results of accessibility analysis and amended schedule after selection of a fast food outlet

The additional SubAction is a visit to a fastfood restaurant at 5:35pm with a stay time of 10 minutes. The individual is then able to travel on to the railway station at 5:47pm and arrive in time to get the train at 6:00pm. The black symbols in Figure 17 represent those fastfood restaurants that are not accessible due to the time constraint of catching the train, and therefore can be removed from consideration with spatio-temporal filtering. This results in 17 possible alternatives becoming suggested from a possible total of 54 restaurants in the spatio-temporal domain. Selecting any one of these 17 should allow Frank to then catch his train leaving form the main station at 6:00pm.

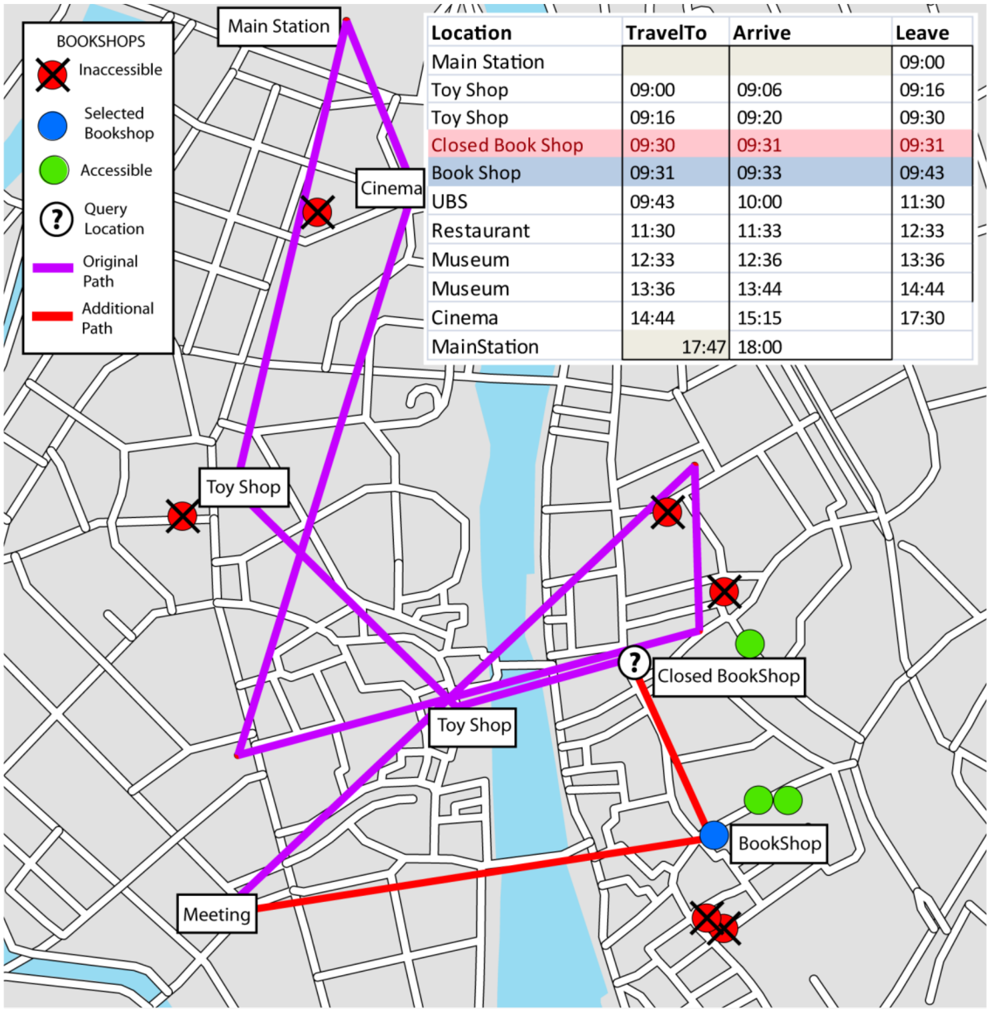
4.5.2 Remove and Addition Scenario

It is of course possible that unexpectedly a location that is included within the plan is not suitable for the desired action, and this is only clear when the individual reaches the location. This could occur because of a lack of data, or an error from the user during the planning phase. An example might be a bookshop that sells books in a language not understood by the individual, or something that is not operational such as a broken ATM. This then requires the plan to be amended by first removing the SubAction that relates to the current location and then adding a replacement if there is sufficient time. The scenario gives a more specific example of how the analysis can deal with such a situation:

Frank reaches the bookshop at 9:30am only to find that it is unexpectedly closed, he therefore needs to find another bookshop. He therefore queries an application on his mobile system to find a Bookshop nearby that he can visit and still make his meeting at 10:00am - Amendment = Remove{BookShop: 9:30-9:42}

→Add. {New BookShop: Start 9.31am}

The first removal amendment results in a time window which allows for another bookshop to be added to the plan and this would therefore require another search to be initiated by Frank to choose a replacement for the closed bookshop. The results of the amendment are shown in Figure 18. As there is relatively small amount of time between the start of this renewed search and the next spatio-temporal constraint (the meeting at UBS) only 4 bookshops (shown as red symbols in Figure 18) are accessible out of a possible 16, and therefore the choice set is limited by the proximity of the next fixed spatial temporal constraints.



Location	TravelTo	Arrive	Leave
Main Station			09:00
Toy Shop	09:00	09:06	09:16
Toy Shop	09:16	09:20	09:30
Closed Book Shop	09:30	09:31	09:31
Book Shop	09:31	09:33	09:43
UBS	09:43	10:00	11:30
Restaurant	11:30	11:33	12:33
Museum	12:33	12:36	13:36
Museum	13:36	13:44	14:44
Cinema	14:44	15:15	17:30
MainStation	17:47	18:00	

Figure 18 - Results of the removal a closed bookshop and addition of an open bookshop

4.6 How Much Information to Display?

As discussed in above sections, the Page Set is the subset of objects from the Presentation Set that the information seeker can view and interact with, and is often much smaller than the Presentation Set. A choice must therefore be taken as to how many of these results should be visually displayed to the user. The results above show that the filtering process occasionally leaves large numbers of accessible places. For example, although 257 restaurants are removed during the planning of where to eat, 239 restaurants remain. This represents a very large choice set which would most likely cause visual clutter if all displayed on a small mobile map, and additionally harm the decision making process as too many choices often results in cognitive overload for an individual and thus sub-optimal decision making. There are several further issues that have an influence on this consideration. For example, only 2.3% of information seekers go beyond the 10th web document in traditional searches (Jansen and Spink 2003). The time pressure of mobile settings means this is more pronounced with roughly 60% of searches viewing only the top 3 ranked results (Church et al. 2008). Therefore, from a technical point of view, it would also make little sense to send mobile clients all the objects in the Presentation Set as the vast majority will be ignored by the user and slow the response times of the application. However, as maps and map objects are difficult to compare with lists of web documents, it is important to note that for mobile map displays these findings have limited use. Currently, location based map services take three main approaches; they either present all the presentation set, chunks of it (e.g. the top 10) or one single object, as seen in Figure 19 below. This section therefore seeks to answer which of these approaches is suitable and when.

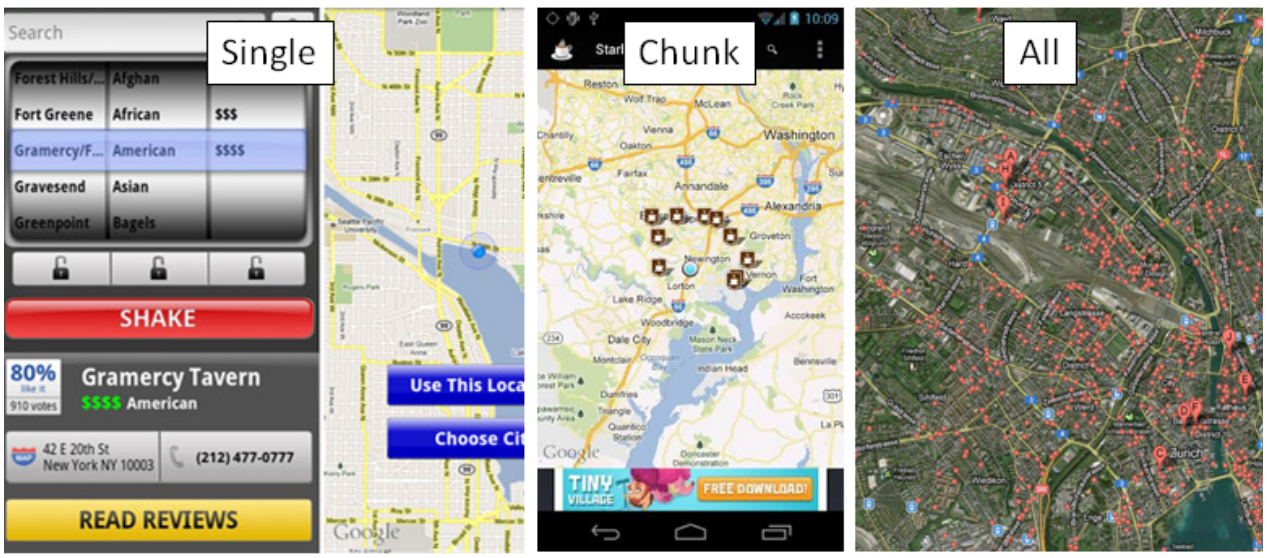


Figure 19 - examples of interfaces showing A) single result (UrbanSpoon), B) Chunk result (CoffeeFinder) and C) All results (Google Maps)

One possible approach is to base it on the three types of information seeking behaviour that a map must support, as defined by (Marchionini 1997). These are shown below in Table 3, and

Information Seeking	**Page Set**
directed browsing	single
semi-directed browsing	chunk
undirected browsing	all

Table 3 - Relating Page Sets to Information Seeking Behaviours

discussed fully in the remainder of this section.

Single – This approach only presents one object to the information seeker, with an interaction allowing the information seeker to scroll from one object to the next. This approach is most useful when the information seeker does not perform decision making strategies that require objects to be compared with one another and has clear information needs. An example of such a decision strategy is found in the concept of satisficing (Simon 1972), which compares each option and selects the first that meets certain internally held thresholds. This type of decision making process is especially applicable to those in an acting phase where activities need to be re-scheduled. When studying how people re-schedule activities that involve traveling between locations in an urban setting, Chen et al. (2004) found that from over 2000 responses related to a re-scheduling task, 98% were not considering options but merely picking the first option that fitted into the new schedule. Furthermore, when navigating, evidence has been found this same type of decision making is used during decision making processes related to the way finding (Tong and Chen 2000). This represents evidence that satisficing decision strategies are being used during the re-scheduling. The clear information needs lead to an information seeking known as direct browsing (Choo et al. 2000), where the goals are clearly specified and directed towards a specific target. As amending the activity schedule results in the knowledge as to when, where and to what the information seeking is directed, this type of information seeking is therefore most applicable to the acting phase.

Chunk – Displaying only a chunk of the Presentation Set has several benefits when decision making will require options to be compared. The number of objects is limited, and therefore the decision complexity can be kept constant however large the Presentation Set. Displaying only a chunk of the Presentation set best supports the information seeking behavior of semi-directed browsing, where a query is launched, and the results are carefully inspected to get an idea of what exists, how it fits to the user's goals, and which might be the optimal choice given the current situation. For the planning phase shown above, this would most likely be the best solution. Commonly systems display 10 objects at one time in each 'chunk', but no empirical investigation has been done in an attempt to validate that this is a good number. However, one user study did discover that displaying only the top five was considered to not be enough (Zhumagulova et al. 2007).

All – Displaying the whole of the Presentation Set could lead to a cluttered display, and has less application for mobile information seeking which is typically time pressured and goal directed, however it may have be applicable in some contexts. When the information seeker is browsing without any specific goal in mind in a situation without time pressure, displaying all the information can support exploratory map use, typical of undirected browsing. The goal of the map interaction would then be to form goals, to get an idea of what actions can be carried out in the location before more directed searching is performed. In these situations it may be important to provide this type of overview by presenting all the results.

4.7 Summary

This chapter represents the first step in the overall work of representing geographic relevance by removing geographic information objects that cannot be physically reached by a mobile information seeker, and which should therefore play no further role in the information seeking process and subsequent decision making. The methodology was informed by the spatio-temporal context of the future plans and the current actions of a mobile individual. The outcome of this methodology was the removal of inaccessible places from the result set. Further filtering of the result set was also described in section 4.6 above, and included three possible filter strategies and which then resulted in a final page set that could be displayed to the user.

The overall role this process plays in the task of developing visual representations of geographic relevance is therefore in the removal of geographic information objects that cannot be accessed due to the space-time constraints to the individual, and is intended to support the activity planning of a mobile information seeker. The following chapter aims to describe how the remaining accessible geographic information objects from this process can be included in the task of designing visual representations, but instead of supporting the activity planning, the aim of this methodology will be to support the cognition of the mobile information seeker during the interactions with the mobile system.

Chapter 5 Applying Cognitive Design Principles to Geographic Relevance Representations

5.1 Introduction

This chapter describes a method that can be applied to develop usable visual representations of geographic relevance. It follows from the previous chapter by taking as input the geographic information objects that remain accessible to the user given their spatio-temporal constraints. The next step in the representation of geographic relevance is then to design visual representations that communicate the geographic relevance in an intuitive way to the mobile information seeker. The method presented here represents a means to develop visual representations through the application of the theory of external cognition, described below in section 5.4. Integrating these theories results in an approach that allows for geographic relevance representations to support the cognitive limitations of a user, and provide a more intuitive communication that makes it clear how the goals and tasks of that user can be related to the visual representation. Relating tasks in the real world to an abstract representation is a process that can be aided through appreciation of these tasks, and this is the approach taken in this chapter.

The general tasks of information seeking in a spatio-temporal, mobile setting will require the individual to comprehend the three basic elements of spatial knowledge - where, when and what (Mennis et al. 2000). This knowledge is important for the user to be able to understand how the geographic information objects presented to them can support their activity at a particular location. This knowledge can then be used as a basis for the decision making that must take place in order to choose one or more of the alternatives from the set of geographic information objects. However, the main argument contained in this chapter is that it will also be important to communicate information to the user that can help them to also understand *why* certain entities/ geographic information objects could be relevant to them. Communicating 'why' is effectively done by first defining the relevance criteria that are applicable to the given task and then designing representations that are adapted to the types of relevance criteria that constitute the geographic relevance of each object. The work presented in this chapter builds on past work that explored and tested the encoding of geographic relevance with visual variables of map symbols (Reichenbacher 2005b). It is very possible that without more explanatory and explicit information, representations of geographic relevance would remain too abstract for naive users to intuitively understand. The main purpose of this chapter is therefore to explore how relevance criteria can be visually represented with the user and their tasks in mind. The general structure of this chapter is to explain how (external) representations can extend cognition, followed by a description of the cognitive resources necessary for the processing of a visual representation and how these can be related to one another. Following from this, an abstract definition of a visual representation is defined, and the various constituent parts of the visual representation that can be amended during the design process. The next step is to then explore each relevance criteria and define how relevance is conceptualised within these criteria. Finally, an explanation of how the developed representations offload the mental processing of an individual for each relevance criterion concludes this chapter. Much of the work in these sections is taken from work first described in (Crease and Reichenbacher 2011).

5.2 How Representations Extend Cognition

A good example of a representational system can be found in cartographical representations, with our cognition of space being not only extended by it, but also developed by it (Lloyd and Bunch 2003). Maps extend cognition through their ability to extend the storage, perception and processing of geographic information (Wood 2001). All representation systems are formed from three main components that allow them to communicate with the individual using that representation, as defined by Norman (1991):

- *The represented world (that which is to be represented)*
- *The representing world (a set of symbols)*
- *An interpreter (an individual)*

One way to measure the ability of the representing world to communicate is through the observation and measurement of the cognitive load imposed on the individual. This cognitive load can be divided into three components of intrinsic, extraneous, and germane (Bunch and Lloyd 2006). Intrinsic load is related to the complexity of the information that must be represented, extraneous load relates to how the information is then represented and germane load is devoted to the development of information structures in the long term memory. Most research focuses on how information design can support the extraneous and germane loads, as these are more readily manipulated (Paas et al. 2003). The methodology described below therefore associates most readily to the second and third elements of the representational system described above. One theory that has been recently put forward and has been drawn from a wide range of literature is the theory *external cognition* (Scaife and Rogers 1996). This theory describes the characteristics of a visual representation that allow it to successfully guide the information processing and knowledge development of the interpreter. This results in three main characteristics that can be used to examine the value of any given visual representation:

Computational Offloading – this characteristic describes how different representations of the same problem can influence, positively or negatively, the mental processing required interpreting an external representation and generating a solution. High computational offload means that many of the cognitive tasks are transferred onto the representation, meaning lower cognitive loads for the interpreter. This idea is in some way analogous to the idea of 'Knowledge in the World' versus 'Knowledge in the Head' proposed by Norman (2002, Norman 1993). An example would be the difference between the multiplications of two large numbers with the use of pen and paper versus with the use of a calculator. The calculator removes the need to perform numerous multiplications in the head, a similar role is played by signs during a wayfinding task (Raubal 1998). For spatial representations differences in offloading exist between pictorial representations versus linguistic representations of space. Pictorial representations hold implicit information that can communicate complex spatial layouts, share spatial constraints with the represented world and can be visually processed in parallel (Habel 2003, Tversky and Lee 1999, Peuquet 2002). Deriving these characteristics of spaces from verbal descriptions requires more cognitive processing, which can make them unsuitable or at least less efficient for certain tasks.

Re-Representation – Utilising structures that are familiar can facilitate the deciphering or manipulating of a graphical representation. An example can be found in the study of (Zhang and Norman 1994) and their use of the Tower of Hanoi problem which demonstrates how problems with the same abstract structure but represented differently alter the efficiency and accuracy of subjects to solve problems. A cartographic example can be found in the discussions by Bertin (Bertin 1983) on visual variables and their relationship with the levels of measurement of the data that must be represented. Ideally the structures used are intuitive to the user of the representation, as they are based on past experience.

Graphical Constraining – Representations can lead, if poorly designed, to an incorrect inference based on misinterpretation. Often it is possible to design a representation in such a way that any expected incorrect inferences cannot be possible drawn from it. An example of these ambiguities in maps could be found in confusion over figure-ground relationships that can be removed with the proper application of visual emphasis techniques (Tomaszewski 2007).

Taking these ideas allows a conceptual model of external representation use to be formulated, with the three characteristics above being incorporated to relate the cognitive resources and task of the user to the external representations. Figure 20 shows how these three elements fit together, beginning with relevance criteria which then require cognitive tasks to be carried out, eventually leading to actions that result from the new knowledge developed by the cognitive processes working upon the external representation. The cognitive faculties of a user and the representation are linked by the three characteristics of external cognition, with the link determining the number of cognitive faculties that must be employed and to what extent. The cognitive resources defined in this model come from the definition given in Section 3.4.1. It is assumed that cognitive faculties can be systematically supported by external representations to solve a certain task. For example, the use of a simple paper map would naturally involve users directing their visual attention towards the map whilst also needing to apply higher level forms of cognition, such as using reasoning, and making decisions on future actions. *External cognition* represents a relationship between the representation and cognition; if the representation mediates a task by supporting the cognitive processes necessary to solve a task then this relationship is a positive one. Types of visual representations that support *external cognition* can been divided into 11 different categories (Lohse et al. 1994). Of these 11 categories maps, networks (e.g. the London Underground Map), and cartograms play perhaps the most influential role when the task at hand relates to actions in geographic space and geographic knowledge is to be used.

Importantly, these three types of external visual representations of space are strengthened by their ability to abstract. This allows them, for many use cases, to be efficiently employed in the solution of problems by focusing on fundamental aspects of the represented phenomena while neglecting unnecessary details. Similarly, the explicitness of information in map representations has the potential to ease the cognitive processing and make it more efficient. The explicitness, the abstraction, and the analogue character of map representations also may release capacities of visual attention, memory and conscious thought (the Cognitive Faculties in Figure 20). They support human cognitive processes by acting as a means to store information about our environment, thereby working as an external form of memory. Visual representations are also simplifications of the real world and contain, when well designed, only the relevant features that directly relate to the tasks of the map reader thereby directing attention effectively and supporting visual cognition. Most crucially they allow us to perceive geographic information over large-scale spaces that humans could not otherwise directly perceive and therefore can positively influence our reasoning and decision making. All this can reduce the cognitive workload for user interaction and allows cognitive resources to be better employed for higher-level processes, such as planning, decision-making, or problem solving, e.g. (Tversky 2005, Swienty et al. 2008b).

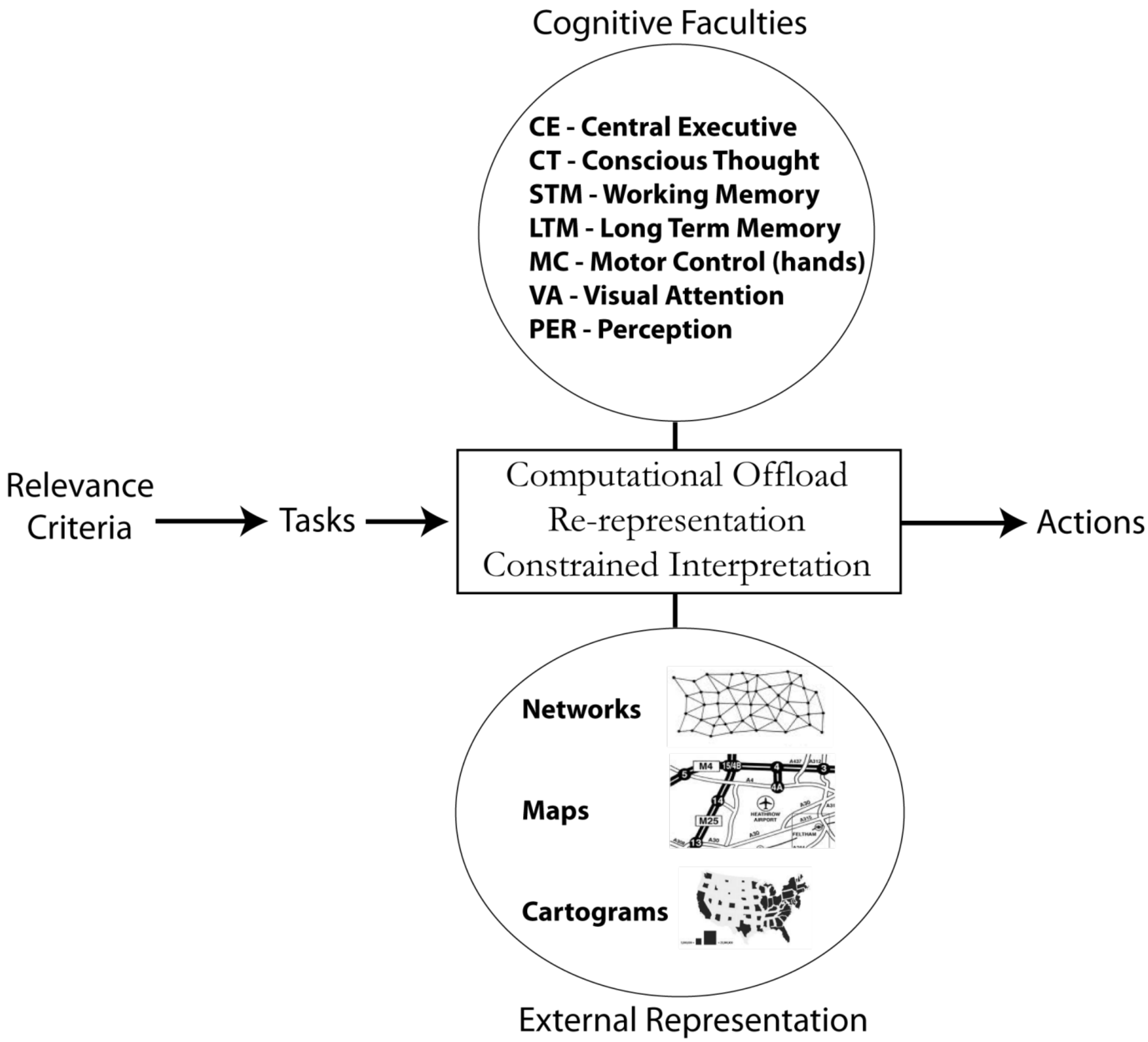


Figure 20 - Relationship between relevance criteria, tasks, and actions based on Oulasvirta (2004) and Lohse et al. (1994)

5.3 How representations might hinder cognition

Although external representations potentially offload cognition, they can also introduce cognitive overload, if designed improperly (Navarro-Prieto et al. 1999). From a multiple resource perspective, this overload can result from the capacity limitation assumption that is applicable to each of the cognitive faculties described above. A good example is a cluttered display which will overload the visual attention, or an interface that requires a large amount of information to be held in working memory. Poor design choices create overly complex visual representations, and it is this complexity that hinders the cognition of the interpreter. Visual complexity can be defined with regard to the absolute number of map elements, their relative density, their level of detail (e.g. form complexity or number of colour values or hues), the visual structure (number of discrete, disjoint objects versus connected or associated objects), as well as the presence and number of labels (Reichenbacher 2009a, MacEachren 1982, Fairbairn 2006).

On higher levels of cognition, it is not only the representation that hinders the ability of an individual to make sense of a visual representation, but also the phenomena represented. This can be found in work by (Castner and Eastman 1984), who differentiate between complexity that relates to a map’s function, and complexity that relates to its form. As a third type of complexity one might add the semantic complexity, i.e. the number of different types or categories in a representation (Reichenbacher 2009a). The semantic complexity of a representation rises with the number of distinct types or categories represented. Visual and semantic complexities are not necessarily related. A large number of objects of the same category yield a representation of high visual, but low semantic complexity. Means to design map representations that lower the complexity support cognitive processes are shown in Figure 21.

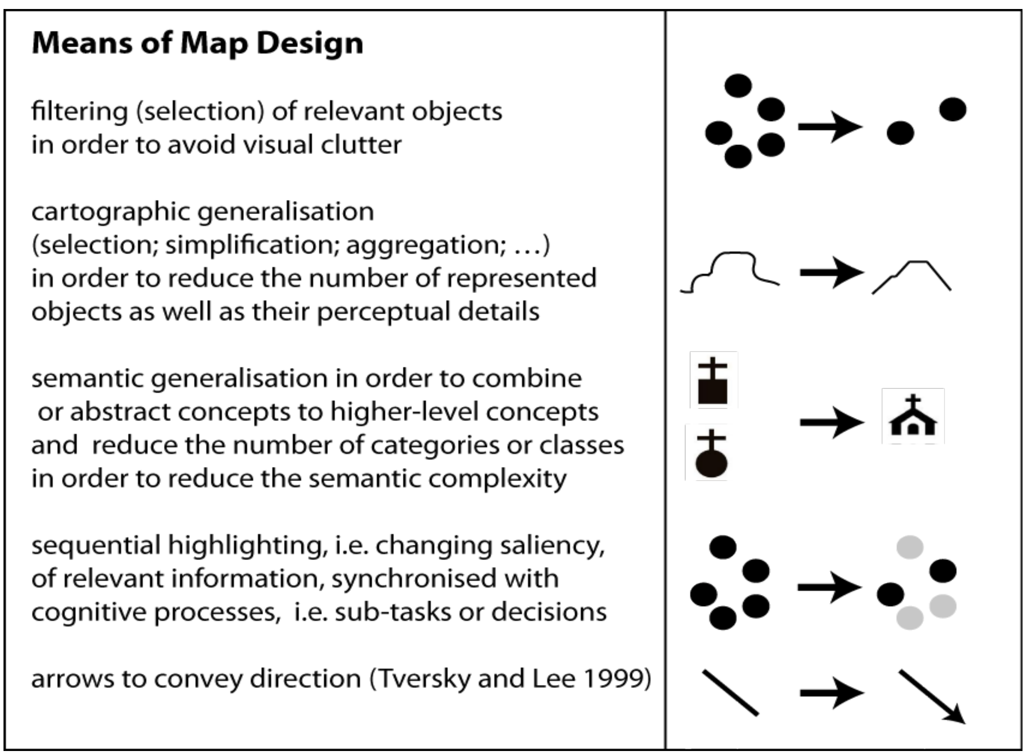


Figure 21 – Means of map design to support cognitive processes – an exemplary use case of a relevance representation in LBS

They include the removal of information, such as the filtering described in chapter 4, or the amendment of existing information, such as generalisation or sequential highlighting. The focus of the work that will be described focuses on the amendment of existing information.

5.4 External Cognition of Relevance Symbolisation

Encoding relevance values with map symbols has perhaps received the most attention so far in research about geographic relevance (Reichenbacher 2005b). This process involves finding visual variables that offer attention-guidance and intuitive mapping to values of relevance. Studies in other contexts of research, like those of Garlandini and Fabrikant (2009), give some ideas regarding visual variables, such as size, colour hue, orientation and colour value, and how they can be used to attract attention of a user. These visual variables allow users to direct their visual attention efficiently to the most relevant location and, if understood, to compare the relevance of the objects during a decision making process based on these relevance values. From an *external cognition* perspective, this symbolisation can aid the efficiency of the interaction in several ways. From a re-representation perspective, the visual variable chosen should be one that is both familiar to the user and provides a mapping that fits the relevance criterion being represented.

The other benefit that comes from encoding these relevance values into the visual appearance of the map symbols is that it allows the information seeker to more readily comprehend the degrees of relevance for the geographic information object symbolised on a map. As these relevance values are a combination of several separate relevance values for different relevance criteria, doing such calculations mentally would be prohibitively difficult for a user. Each geographic information object would require the results of these calculations to then be compared, which would most likely exceed working memory resources of the individual and lead to sub-optimal or failing decision making. Visualising these values of relevance is therefore a method that can offload mental information processing. However, a key question still remains as to the intuitiveness of the visual representations. If the user is able to comprehend the meaning of these visual variables, then it will be possible to guide the decisions towards the more relevant objects and the less relevant objects can be selectively filtered from the user's choice set. This is a form of graphical constraint as it restricts against the user investigating irrelevant geographic information objects in more detail. As these investigations will often mean further interaction with the mobile device such an approach is in favour of overall usage efficiency.

5.5 Methodology

This section describes a methodology that allows the development of visual representations that can offload cognition, remove the possibility of incorrect interpretation and use familiar means to communicate spatial concepts. The aim of this methodology is to identify the type and form of elements of a map representation that can be utilised in a mobile map design process. Based on analysis of the relevance criterion and the cognitive tasks required to perceive this criterion, these elements can then be formed during the construction of a representation. The form they take is decided by the concepts of external cognition described earlier. This section therefore builds on the definition given by Scaife and Rogers (1996) of external cognition, and offers a contribution by demonstrating how these ideas can be applied to improve the communication of geographic relevance.

Increasing the cognitive offload of the visual representation is dealt with by analysing the relevance criterion to discover what forms of information should be made visible to the user, for example overlaying a route so the individual can assess the directionality of the objects. Additionally, this analysis will also determine the states of certain features of the map representation, such as its orientation to the direction of travel. To begin, each geo-object is defined as *geoObj* = $<x, r(v)_1 \ldots r(v)_n, R_1 \ldots R_n>$, which represents a single location with a number of relevance criteria and relevance values for each criterion. The input is then a set of geo objects *GeoObjSet* = {$geoObj_1 \ldots geoObj_n$}. However, it is not the data representation that this thesis is concerned with, but rather with making this data representation perceptible and therefore the aspects that affect how the relevance of the geo-objects in *GeoObjSet* is perceived must be defined. These aspects come from work by Barkowsky (2002) into how geographic information is processed and include dimensionality, object/field, vagueness, spatial scale, frame of reference and relationship explicitness. These aspects are divided into the categories of cognitive offload, graphical constraining, and re-representation described above. The state of a representation can then be defined by parameterising these aspects; the possible parameters for each element are as follows:

Representation State (RS) = GeoObjSet {(d, of, v, s, r, er}

where:

d = Dimensionality = (point, area)

of = object/field = (object, field)

v = vagueness = (crisp, fuzzy)

s = spatial scale = ($X^{lowerleft}$, $Y^{lowerleft}$, $X^{upperright}$, $Y^{upperright}$)

r = map orientation = (allocentric, egocentric)

er = explicit spatial relationships, e.g. route information, cluster locations.

The default representation in an unadapted state (shown in Figure 3) can then be represented as:

Default Representation State *DRS* = *GeoSet*{ d(point), of(object), v(crisp), s(*GeoSet(Extent)*), r(allocentric), er(null) }

(where *GeoObjSet(Extent)* = the extents of the geo object dataset)

This map state (DRS) is based on the cartographic representations used within a typical LBS map service, and therefore this work will explore how transformation can be applied to it to enhance the ability of an individual to seek information based on the geographic relevance criteria. An example of a default representation is shown in Figure 22, which contains a point of interest layer overlaying a basemap. To move from the current state (DRS) to another state, it is necessary to change one or more parameters using a transformation. These transformations can alter the parameter values of the current map state to those of the target map state, through amendments to the content and method of presentation. These transformations will be either the simple application of graphical effects, e.g. overlaying a map layer, or require contextual analysis in order to generate information that can then be used to alter one or more of the parameters. For example, rotating the map towards the direction of travel through analysis of GPS tracks will result in the *r* parameter changing from allocentric to egocentric. The type and nature of the transformation will be based on the relevance criterion that needs to be represented and the associated visual and interactive tasks that this criterion then requires. The aim of these transformations is cognitive offload for the user. Transformations by the system remove the need for the information seekers to carry out the transformations themselves employing cognitive resources. An example of this would be mental rotation performed on a map state that has a north-aligned frame of reference (allocentric) in order to understand directions. Transforming the map state to a head-up alignment (egocentric) through analysis of GPS data results in these mental rotations becoming unnecessary. Therefore, the greater the total number of differences between the parameters of the target map state and the default map state the greater the amount of cognition that must be focused on the map in order for the relevance criterion to become apparent.

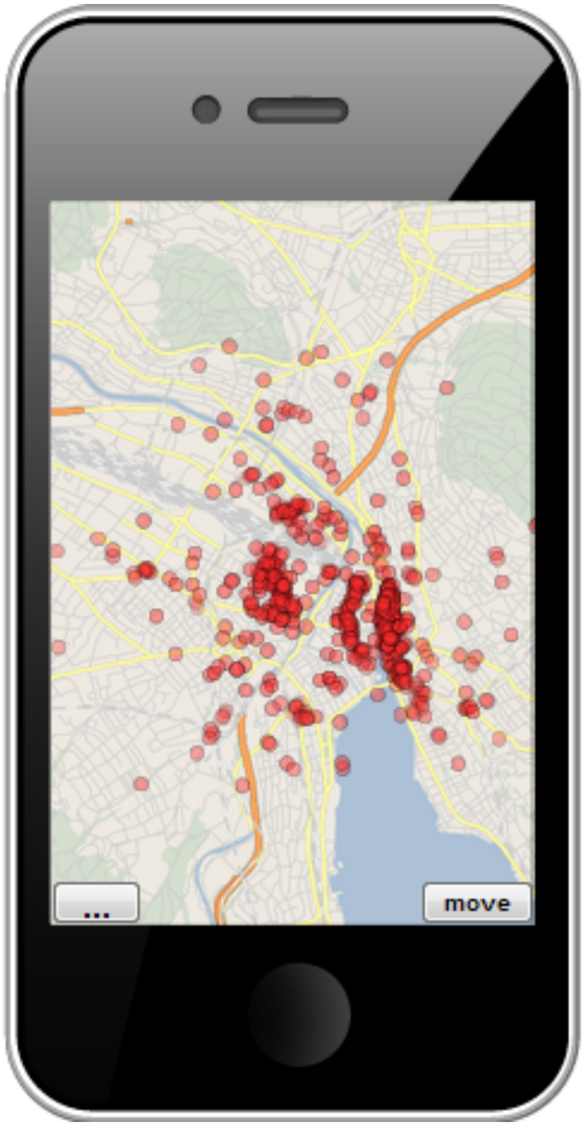


Figure 22 – Basic visual representation used for the initial analysis

Additionally, the design process will seek to identify possible incorrect interpretations and incorporate constraints. Once the mental tasks and potential misinterpretations have been defined, an adapted design will be proposed that will better support the individual's task. This process will be carried out for the relevance criteria of directionality, spatio-temporal proximity, co-location and clustering. Furthermore, to better explain the process, each relevance criterion will be introduced through an example scenario which will then be related to a task analysis. The next section defines these target states for each relevance criterion using analysis of the context from scenarios to inform the parameterisation of the target representational states. The methods used to graphically constrain and re-represent the information are also discussed for each relevance criterion.

5.6 Adapted Representation States

This section introduces a scenario to communicate how each relevance criterion relates to a real life problem or task and discusses the cognitive offload, graphical constraining, and re-representation involved. The description of the target map state is based on methods to offload cognition onto the map representation. The graphical constraining and re-representation are used to adapt or add visual elements to the default representation. The parameters for the new map state that differ from the default map state will be emphasised in bold. In defining these new map states the cognitive offload, familiarity and necessary constraints are also considered.

5.6.1 Co-Location

"Julia plans a train trip to visit Zurich over the next weekend, a city to which she has not yet been. She uses a mobile mapping system to find a hotel at which to stay. During her stay she wishes to go for shopping clothes and visit some of the sights of Zurich, so the hotel should ideally be located close to other locations that support these activities."

Cognitive Offload - The co-location relevance criterion is allocentric as its calculation is not based on the location of the information seekers current location. Instead the co-location relevance of a geographic information object results from its proximity to other related geographic information objects. This criterion will therefore be applied in contexts related to allocentric geographic information needs, where the actual physical location of the information seeker plays little role in the relevance of the geographic information objects. The scenario above displays an example situation, where an information seeker must understand what the relationship is between a set of geographic information objects, and a set of locations relevant to one or more chosen activities. The discovery of the co-location relevance for the given scenario would require the visual analysis of two layers that contain locations relevant for both shopping and sights. The task is then to find hotels that are located within areas with high densities of places that support shopping and sightseeing. For the co-location criterion, the relevance is distributed over spatial areas as it varies continuously with the density of the shopping and sightseeing objects and contains no hard boundaries. This results in a target map state as shown below:

CoLoc-MS =

GeoObjSet {CO(d(**areal**),of(**field**),v(**vague**),s(extent),r(allocentric),er(**spatial density, type**)}

To move from the default map state (RS) to the map state defined above (CoLoc-MS) requires information seekers to perceive vague areas of high spatial density of these related places in the overview phase, so that this area can be focused upon during the more detailed comparison. This results in the need to perform a transformation that analyses the density of these objects.

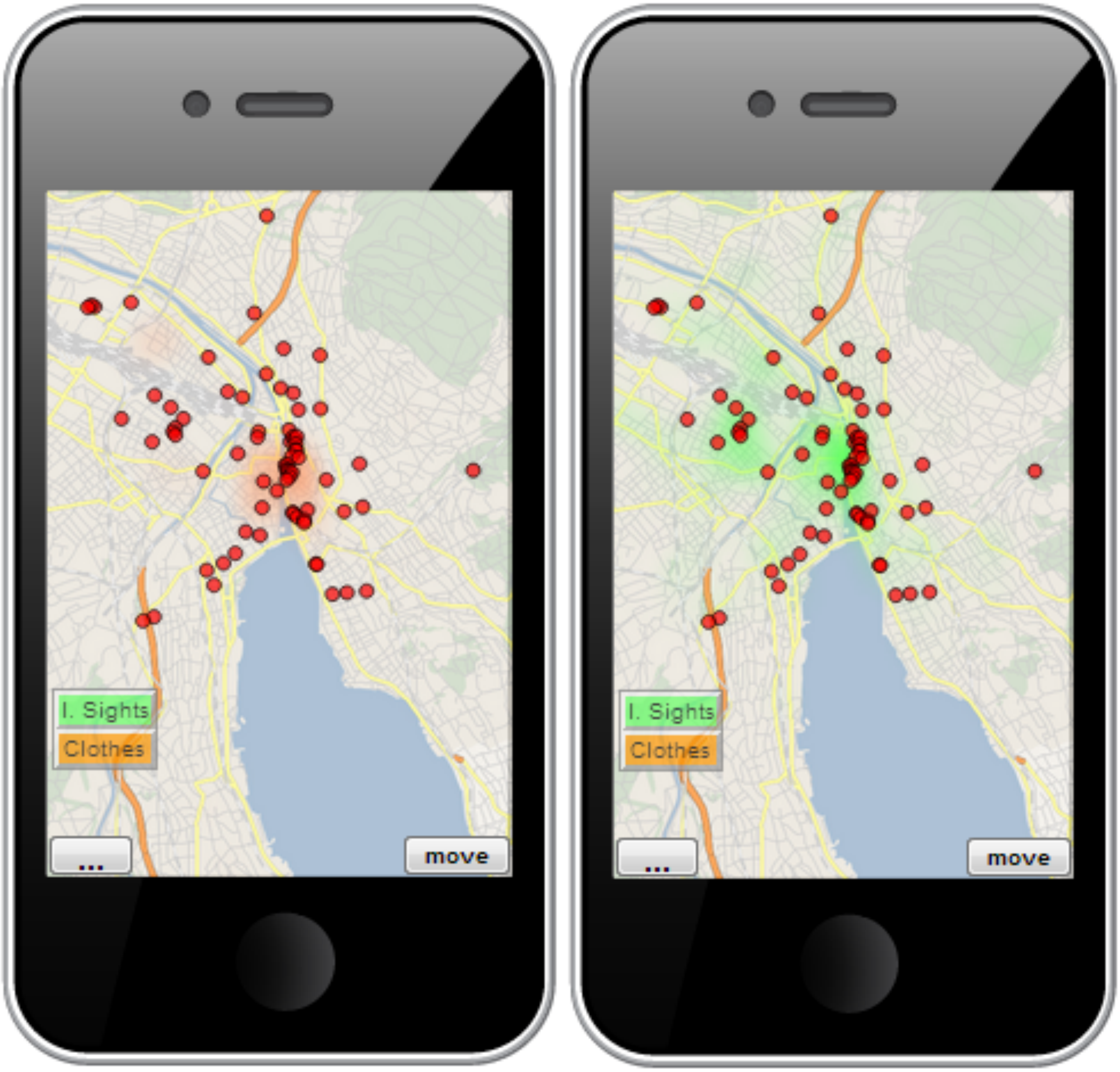


Figure 23 - Co-Location Map States for Clothes Shops (left) and Important Sights (labelled = I. Sights) (right)

One method to support this visual task is to calculate the density through the application of a kernel density algorithm, as this outputs a raster data structure that can communicate the gradual change over space required by the *of* parameter in the above equation. The co-location is reliant not only on the density of objects, but also on the type of object. In the scenario above, the examples given are clothes shops and sights. Therefore the type of objects that constitute these density surfaces must be communicated. This results in the *er* parameter needing to explicitly represent both spatial density and type. As the information seeking is still allocentric and an overview is required, the map extents (the s parameter) are set to those of the dataset and the alignment of the map does not need to be adapted. An example implementation of the target map state (CoLoc-MS) is shown above in Figure 23, showing the density surfaces for clothes shops and sights calculated using a kernel density algorithm.

Graphical Constraining – Buttons on the left of the interface allow the visibility of the surfaces to be toggled. The button is given a label of the activity and the same colour hue as the density surface, so that the individual can easily understand which button shows which surface and how this relates to the chosen activity.

Re-Representation - Cartographic theory suggests that more intense colour values are intuitively mapped to higher values of a variable; therefore the re-representation of the density is supported by colouring more dense areas darker using higher opacity values.

5.6.2 Cluster

"After arriving in Zurich on Friday evening, Julia plans her shopping trip for the next day. She is interested in finding shopping areas for the following day's shopping trip, and uses a mobile mapping system to search for the main shopping areas in Zürich."

Cognitive Offload - Clusters are, like co-locations, allocentric. The relevance stems from the density of geographic information objects, more densely clustered geographic information objects result in them becoming more relevant. Cluster relevance is therefore calculated using the ratio between the number of objects within a cluster and its spatial extents, as well as the distances between related objects within the cluster. The information seeker must first identify these areas of high density and compare them, before choosing the densest. The scenario above describes a situation where cluster relevance is utilised to help the discovery of shopping areas.

A shopping area is clearly cognitively conceptualised as a region, albeit one with vague boundaries. This observation can be seen in work by Montello et al. (2003) into vague regions, and the definition of a shopping area using the image schema concept of REGION in Rüetschi and Timpf (2004). Therefore the target map state for these shopping area objects is shown below

Clust-MS =GeoObjSet {d(**areal**),of(**object**),v(**vague**),s(extent),r(allocentric),er(**cluster centre**)}

This representation should therefore communicate vague areas which are formed from groups of individual point geo-objects. The spatial clustering algorithm applied during the calculation of density relevance criterion results in the individual geo-objects being assigned to cluster groups. Although these clusters of objects could be explicitly represented by visualising the extents of each cluster, the clusters are represented as map symbols for reason explained in the graphical constraining sub-section. These map symbols are positioned at the mean centroid of each cluster group. As the perception of a cluster on overview maps can be hindered by visual clutter, only three most dense clusters are displayed and each cluster map symbol is interactive. Touching or clicking on one of the point symbol zooms and pans the map automatically to the extents of the cluster, to remove the need to manually zoom and pan to the correct extents.

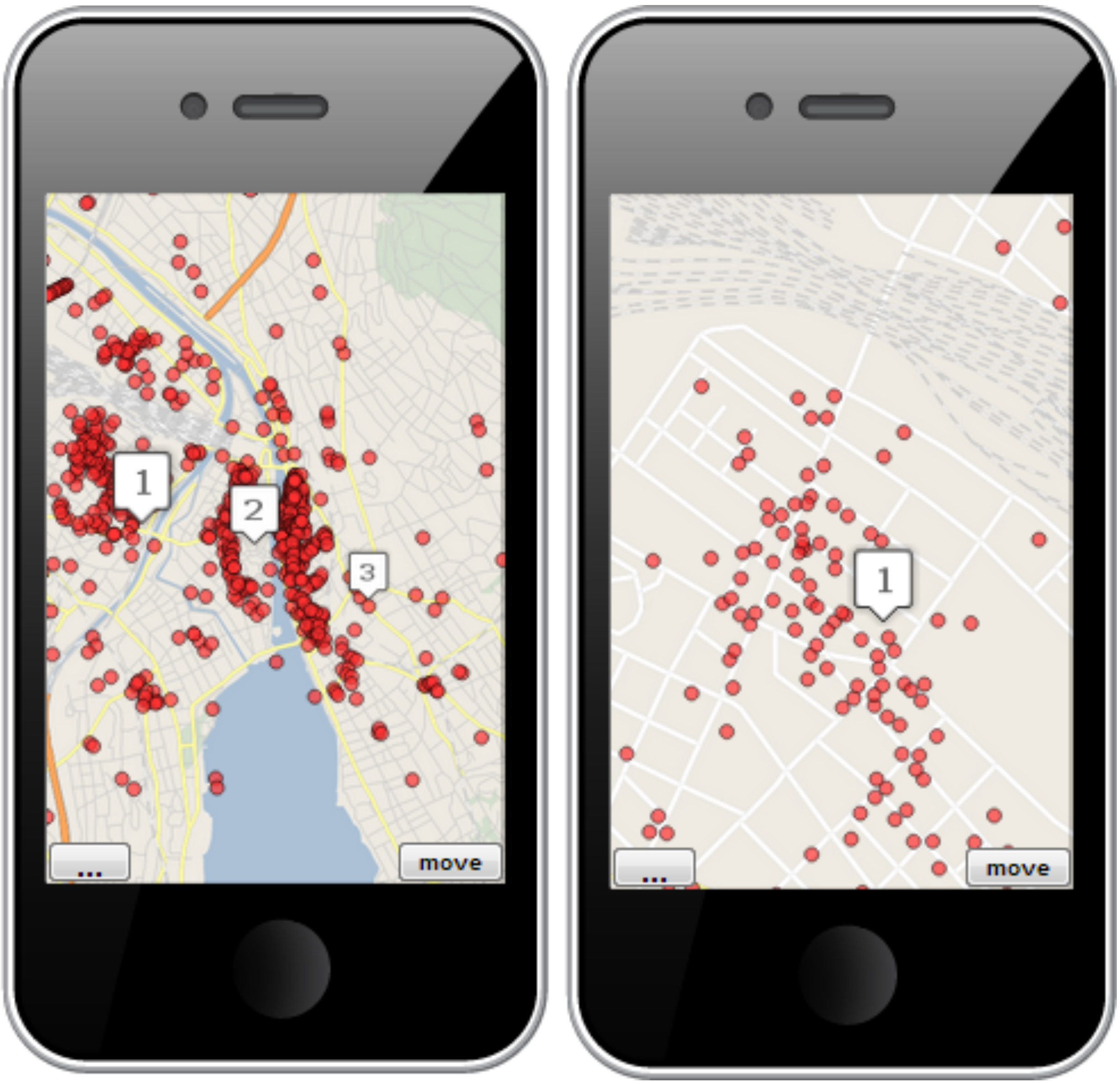


Figure 24 - Maps adapted to cluster relevance - the overview (left) and the detailed view shown after clicking on cluster ranked as the most relevant (right)

Graphical Constraining - One method to represent these clusters would be through explicit representations of the clusters as regions on the map or as a density surface. However, it is well understood that size is often related to importance and that relevance of a cluster is not dependent only on its density. This could therefore lead to incorrect perceptions regarding the relevance of a cluster, and so graphical constraints are employed to avoid this. The clusters are therefore represented by point objects located at the centre of the cluster (see Figure 24).

Re-Representation – As the size of an object is related intuitively to its importance, the visual variable size is employed to communicate the relevance of the cluster map symbol. Additionally, each symbol displays the rank of the cluster (from 1 – 3). This rank is generated by summing the cluster relevance criterion of all objects within each cluster group, and taking the three with the highest values. An implementation of such an adapted map is shown below in Figure 24.

5.6.3 Spatio-Temporal Proximity

"The hotel where Julia is staying does not serve breakfast. Therefore she searches for a place to buy breakfast on Saturday morning. She wants to find a place that is within a 10 minute walk from the hotel."

Cognitive Offload - The spatio-temporal proximity relevance criterion can be both egocentric and allocentric. It could be measured using the mobile information seeker's current location to the geographic information objects, or it could be the distance from a landmark, e.g. the main station, to the geographic information objects. The type it takes comes from the context of the user, and more specifically from the planning or acting contexts mentioned in chapter 4. Despite this difference in context, the visual and cognitive tasks remain very similar for both actors and planners, with the basic perception of spatial distance from a specified location being translated into spatio-temporal distance.

This scenario represents a need to delineate a spatio-temporal boundary, and discover geographic information objects located within a specific distance of 10 minutes. To judge whether the geographic information objects are within the boundary will require an explicit visual representation of the boundaries' location. Then the individual is able to judge if the geographic information objects are within the boundary or not. Also necessary will be the origin (or: point of reference?) to judge the spatio-temporal relevance of those objects within the boundary. This origin will be the current location for an egocentric context, and a landmark for an allocentric context. Therefore the target map state for this relevance criterion is as shown below:

STP-MS = *GeoObjSet* { d(**point**), of(**object**),v(**fuzzy**), s(**spatio-temporal boundary**(***Extent***)), r(allocentric), er(**origin, spatio-temporal boundary**) }

The representation aims to communicate to the user which objects are within the boundary and to what degree these objects are proximal to the current or planned future location. The scale of the map is also set to the spatio-temporal boundary, as Raubal and Panov (Raubal and Panov 2009) suggested this should reduce the cognitive load of the individual user due to the removal of the need to manually zoom the map. The example of this map state is shown in Figure 25 below.

Figure 25 - Maps adapted to spatio-temporal relevance; areas accessible within the time budget are highlighted. The chosen time budget is shown on the left of the interface

Graphical Constraining - Explicitly visualising the area accessible within the time limit specified allows the individual to perceive which objects meet the criterion, and which do not. This prevents the user from perceiving geographic information objects as being accessible when in fact they are not.

Re-Representation – The area of the map that is accessible is highlighted to allow a clear differentiation between the areas which are accessible and those that are not accessible. Furthermore, a graphical effect is applied to blur the boundary, and to represent the uncertainty as to its exact location. This uncertainty stems from the fact that the algorithms used to create these boundaries will incorporate uncertain predictions of travel speeds, and incomplete street network datasets. This method of visually blurring a map object has been shown as an intuitive way to represent uncertainty (MacEachren et al. 2005, MacEachren et al. 2012)

5.6.4 Directionality

Julia needs to catch her train back to Italy on Sunday evening and on the way to the station she requires an ATM so that she can buy food on the train".

Cognitive Offload - This criterion is egocentric, as it is derived from the movement of an individual towards a specified location. The aim of the representation for this criterion is to communicate the degree to which each geographic information object is located in relation to the future movements of the individual. This relevance criterion also varies gradually over space, and so is best seen as possessing vague boundaries. To make a judgement about direction it will be necessary to explicitly represent the origin (current location) and destination, and the path between these two. Additional research by Winter and Tomko (2004) suggests that orientating the map representation to the direction of travel and placing the current location of the map at the bottom of the map screen will benefit the perception due to the orientation of the map matching the perceived environment.

DIR-MS = *GeoObjSet* { d(Punctual), of(**object**),v(**vague**), s(**origin-destination(extent)**),
r(egocentric), er(**origin, destination, planned route**) }

An implementation of a map interface adapted to directionality is in Figure 26, and is discussed below. The transformation process for this relevance criterion will require contextual information regarding the current location and the destination of travel. This contextual information can then be fed into a network analysis algorithm to calculate the shortest route between these two locations, and the route overlaid on the map. This contextual information is also used to orient the map according to the direction of travel and set the maps extents automatically to show the origin, destination and potentially relevant geo-objects. This then removes the need to interact with the map to set the correct map extents and therefore represents a cognitive offload. Lastly, this relevance criterion is most likely to be useful when on the move, and therefore is most useful in contexts where interaction with the interface should be limited. Two buttons located at the top of the screen allow the individual to (A and B in Figure 26) scroll from between the map objects in order, showing only one place at a time. This scrolling process is shown in Figure 26, with two interface states being shown as the user scrolls from the most relevant map object (left), to the second most relevant map object (right). This has benefits to the cognitive faculties of the individual associated with the interaction and visual attention. Firstly, the buttons offer large targets which can be easily clicked to scroll to the next object in the relevance ranking. Secondly, the interface is left uncluttered by objects and allows each object and its information to be easily focused upon.

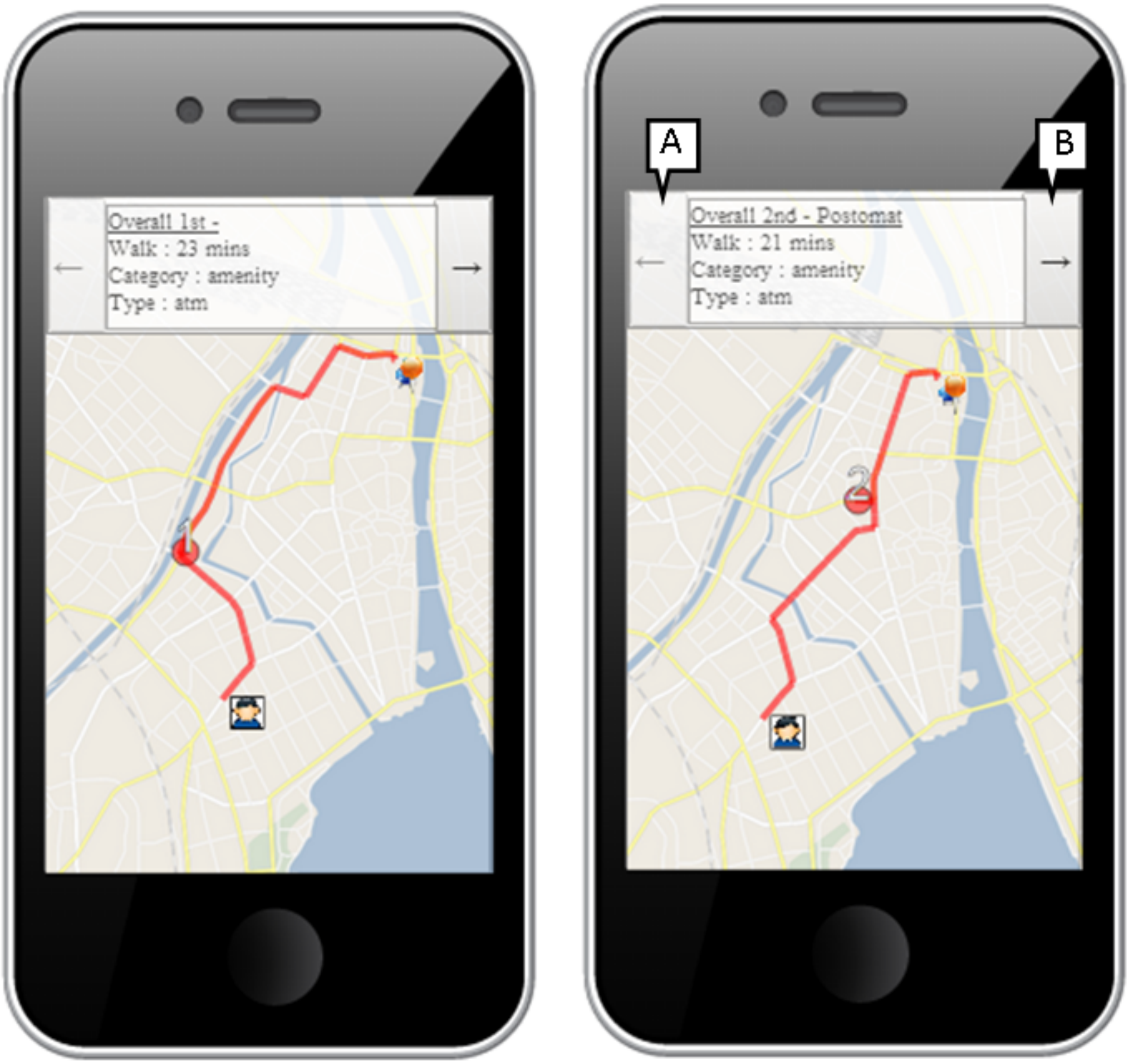


Figure 26 - Maps adapted to the direction of movement (directionality)

Graphical Constraining – Both the origin and destination are symbolised differently to communicate the direction of travel and avoid the confusion of which end of the displayed route represents the origin and which represents the destination.

Re-Representation - the use of a graphical representation of the user (also known as an avatar) to symbolise the current location should allow this symbol to be more easily recognised by the information seeker. Such symbols are regularly employed by current web services to allow the recognition of users.

5.7 Measuring cognitive offload

To partly validate the methods described above, one of the adapted interfaces is chosen and compared to the unadapted interface. This comparison is carried out using the cognitive modelling approaches explained in Chapter 3, and allows the comparison of the interaction of the individual, using CogTool, and the visual cognition, using a model of visual clutter proposed by Rosenholtz et al. (2007). The interface adapted to the communication of directionality is chosen as it offers several unique adaptations to the interaction and visual presentation which can be measured by these tools, and so offers itself as a good example by which to measure what the effects of these adaptations might be.

5.7.1 Evaluation of the interaction offload

A model of the default map representation interface defined above, and a model of the interface adapted to display directionality were created in the CogTool software (John and Suzuki 2009). CogTool is an application that allows predictions of efficiency for goal-directed interaction, calculated on a simplified model of an interface. The model follows that of a key-stroke-level model (Card et al. 1983), but with perceptual and cognitive operations parameterised by findings from past psychological experiments (John et al. 2004). It has been successfully used on a large number of interface design studies and correlates well with observed behaviours from empirical studies (John and Suzuki 2009, Teo and John 2008, Teo and John 2006). The advantage of this software is that it greatly simplifies the process of building a model of interaction, and therefore results in fewer errors during the model building process. The CogTool interface model consists of states and transitions. These states refer to states of the interface and transitions are user generated events, such as button clicks or mouse clicks, which allow the transition from one interface state to another. The model makes one important assumption, that the user is familiar with the system being used. It also automatically assigns 'Think' cognitive actions for 1.2 seconds, and this approach is based on the empirical observations of (Card et al. 1983). These 'Think' actions are not added if the user must repeatedly push the same button, such as repeated tabbing. With the application of CogTool, a simplified model of the low level cognition of interaction is produced. Each interaction is composed of cognitive tasks that represent the employment of vision (eye movement preparation and execution), motor control (hand and finger movements) and procedural memory to solve the given task.

Figure 27 shows an example of how the adapted model looks in the CogTool application, with the arrows representing transitions from one interface state to the next after the button (top right, coloured orange) is pressed. The interaction involved the individual having to create a

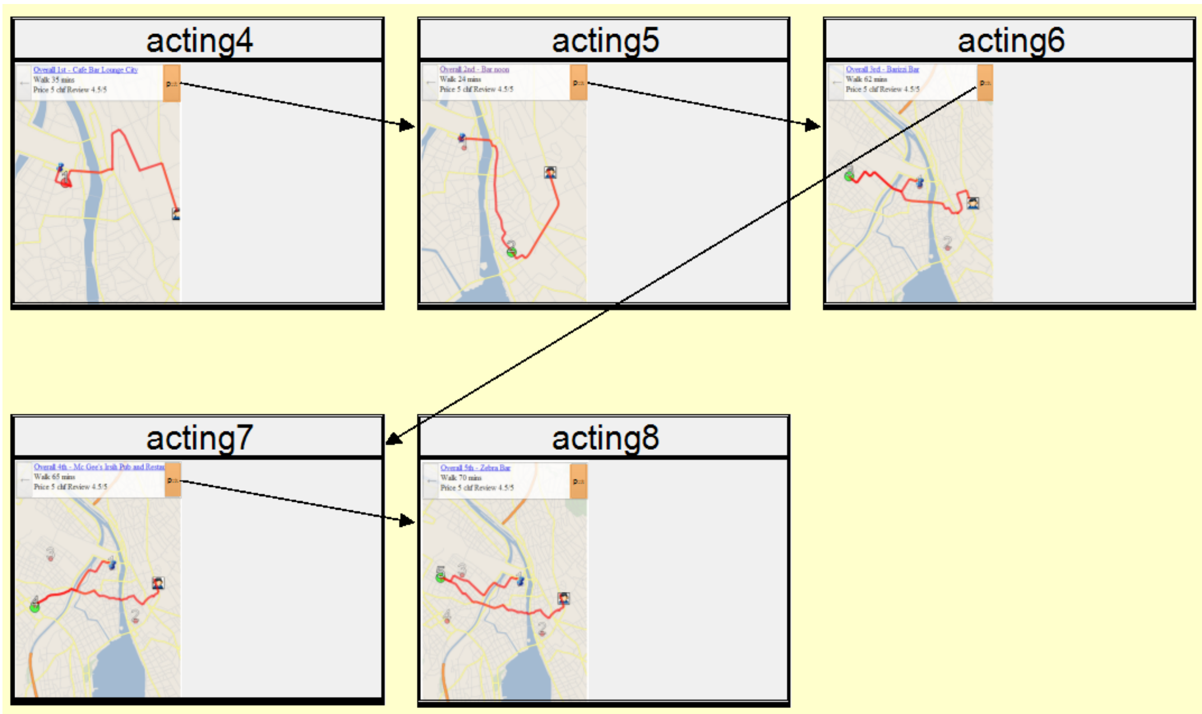


Figure 27 – Screenshot of an interaction model from CogTool, arrows show the flow of interaction from one interface state to the next as the top right button is pressed

route overlay from their current location to the planned destination via a point of interest, in order to get information as to the travel time required to reach the destination. Additionally, the popup label of the point of interest must also be viewed to get an idea of its category type and rating. The interaction model for the default map representation was created based around the interactions necessary whilst using Google Maps Mobile v5.10.0.0 for Android Mobile Phones, as this represents a common mobile map interface and provides a good baseline against which comparisons can be made. This default interface requires several interactions for each point of interest to view its travel time and overlay a route, and the exact interaction can be seen in Figure 28 (upper part) under the default interface title. Additionally, each point of interest must register a click or touch event in order for information to be viewed in a popup label.

The cognitive offload will result from the adapted interface condensing all of these interactions into the click of one button (A or B in Figure 26). Additionally, according to Fitt's law, cognitive offload will result from the button providing a larger target than a map symbol and also having an invariant position on the interface, which then removes the need for visual search to be carried out in order to locate the next target. The model was run for the comparison of 20 map objects, starting with the most relevant and moving to the twentieth most relevant. Figure 28 below shows the times measured for each stage of the interaction, and the overall progression of

DEFAULT INTERFACE

State	Transition	Time Taken
StartingView	-> Click Object	1.552 seconds
Object Information	-> Click Show Direction	1.572 seconds
Direction Interface	-> Click Get Direction	1.625 seconds

INTERFACE ADAPTED TO DIRECTIONALITY

State	Transition	Time Taken
View Information	-> Click Right Arrow	0.392 seconds

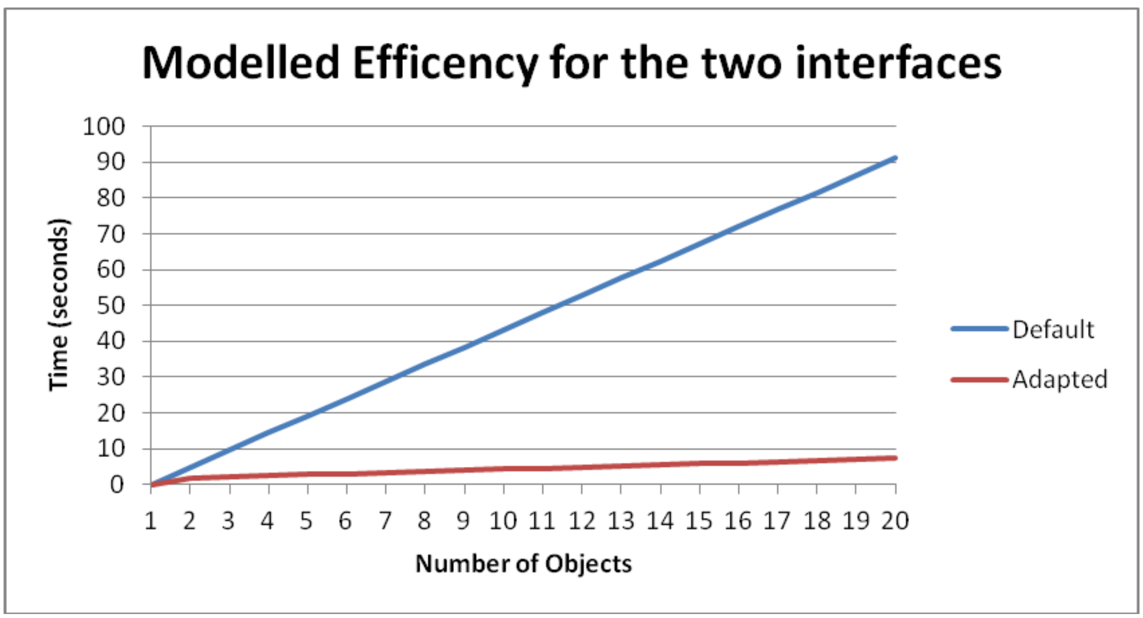


Figure 28 – Above - Transitions and states along with modelled times for one object. Below – the growth of the interaction time with number of objects

interaction time. In total moving from the one object to the next took 4.8 seconds for the default map representation, as the user must first click on the map object (which involves a visual search), then click on show directions in a popup and then click on the button to overlay the route and travel time. The adapted interface took only 0.34 seconds for the adapted interface to display the required information. This resulted in 91 seconds of interaction being necessary to compare 20 objects for the default interface, with the adapted interface resulting in only 7.2

seconds. It is important to note that these values represent only the time taken to perform the interactions necessary to generate the necessary information, and do not incorporate the user having to perceive and understand the meaning of the information being shown to them. It is therefore a measure of the efficiency of the low level cognitive processes involved in carrying out physical interaction with the interface.

5.7.2 Evaluation of the offload to visual cognition

The model of visual clutter applied in this section aims to gauge the ability of an individual to extract information from an image, be it a picture or a map, during a visual search task. This tool was developed by Rosenholtz (Rosenholtz et al. 2007) as a means to measure this visual clutter, and represents a bottom up approach that models the statistical saliency of an image. The model combines measures of colour hue, value and differences in orientations to produce a saliency map for the image and a dimensionless scalar value that represents the measure of visual clutter. It has been verified with map interfaces and found to correlate well to other models of clutter and to human subjective measures of clutter derived from empirical tests (Lohrenz et al. 2009). This model enables map clutter to be quantified with clutter measures, and thereby provide evidence that one display is better able to support the visual attention of another. More visual clutter results in a degradation of performance, as it impedes visual interrogation of the image in order to extract information from it. Supporting the visual attention of the user is afforded by lowering the visual clutter of the interface (Looije et al. 2007). The visual cognition offloaded by displaying only the selected object was measured by taking screen images of the same map extents for each of the twenty most relevant objects. One image had the objects removed whilst the other contained all the map objects, example screenshots are shown below as the top two images in Figure 29.

Removing the distracting objects should result in a lower measure of visual clutter as distracting objects are removed. This was carried out for map images displaying the 20 most relevant objects, moving from the most relevant to the twentieth most relevant object as with the CogTool evaluation. The output of the model is a clutter image (the lower images below in Figure 29) and a dimensionless scalar that represents the degree of clutter. Every adapted map image analysed produced a lower measure for the degree of clutter than for the default map extent. The average of the clutter was M=8.6 for the adapted map and M=5.9 with the distracting map objects removed.

Figure 29 – screenshot of interface with objects removed (top right) and with all objects (top left) and resulting clutter images shown below

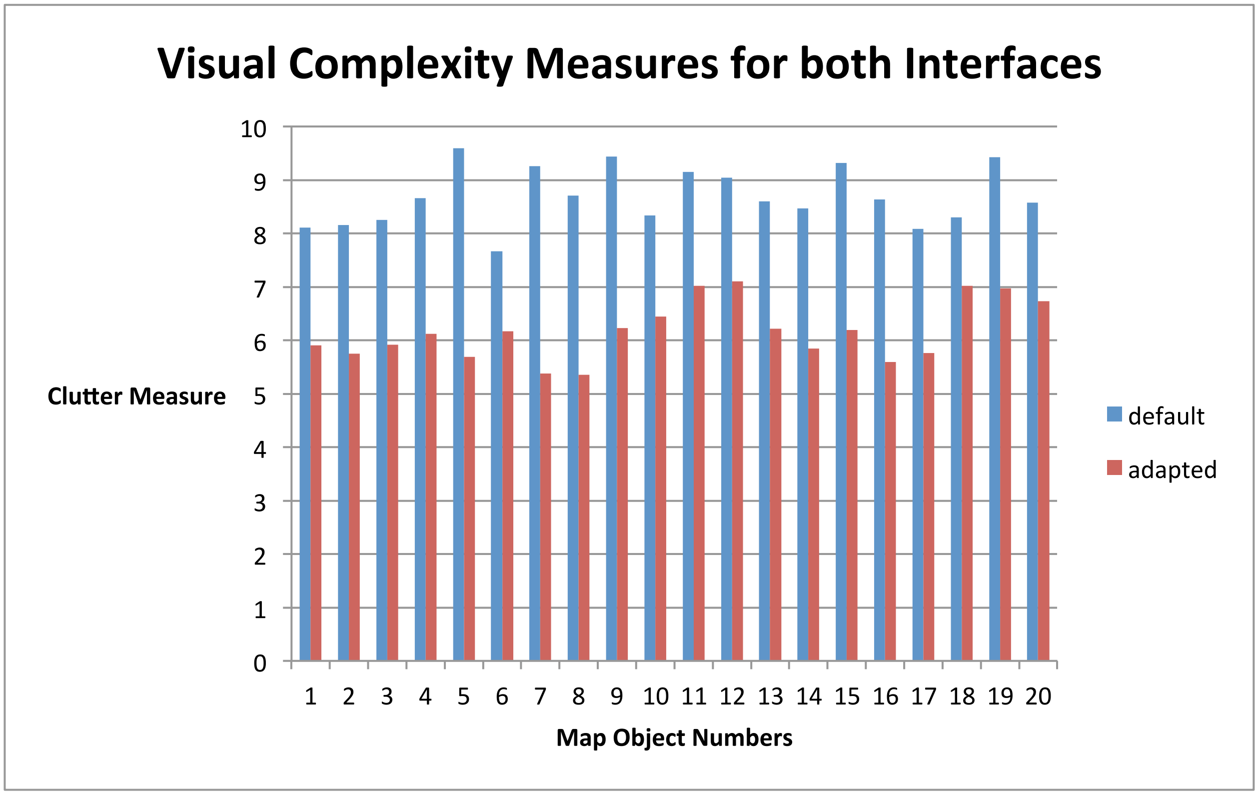


Figure 30 - clutter measures for the default display and the adapted display

5.8 Summary

This chapter focused on describing a method that can enhance the ability of a map interface to aid the cognition of an individual through analysis of the relevance criterion. The output of this analysis is a map representation that contains amended and additional information which allows the individual to be able to judge the degree to which the map objects are relevant for the given relevance criterion. This method incorporated cognitive principles and evidence was found, through the results of cognitive modelling, that these principles can increase the ability of a visual representation adapted to the relevance criteria to remove or offload cognitive tasks onto the external representation. However, the cognitive and perceptual modelling could not validate the two other principles of external cognition - graphical constraining and re-representation - which play a key role in the communication of relevance. These principles help the user not only intuitively understand what, where and when something is relevant, but also why it is relevant, e.g. because it is located along my travel path. The next chapter features a more in depth exploration of how the visual representation here can be made more intuitive and usable through the application of categories and metaphors. Additionally, Experiment III in Chapter 7 describes an experiment based on the visual representation described above for directionality, which aims to see if adding information improves or hinders the perception of the relevance of map objects.

Chapter 6 Categories and Metaphors

The previous chapters introduced methods that filter information, and then can be utilised to add task related information to remove possible misinterpretations and offload cognition. This chapter introduces the application of categorisation and metaphor use to further enrich the visual representation. It borrows from studies carried out into linguistic theories, such as image schema (Lakoff and Johnson 1980) and basic domains (Langacker 1986), and interaction research, specifically faceted search (Hearst 2008) and map interaction (Harrower and Sheesley 2005). The main output of this section is to take this past research and apply it to geographic relevance, in the production of cognitively adequate depictions and interaction methods.

The goal of the categorisation methodology described in section 2.1 is to make the interactions of the information seeker more efficient. The categorisation provides this efficiency, by giving a searchable structure to the various dimensions of relevance. This structure can then be interacted with through a faceted search, which allows an information seeker to rapidly narrow the search space that is being explored. The application of metaphors aims to enrich the interactions, and also offer a means through which to intuitively communicate relevance. The communication of relevance is explored for both linguistic and visual representations. Additionally, interactions metaphors for geographic relevance are applied to a conventional map interface. First the structuring of relevance categories is discussed. This is then followed by a description of methods to categorise individual relevance categories and then by a description of methods to categorise combined values of geographic relevance. Finally, the development of a search interface is described to explain how these methods might be incorporated into an interface design.

6.1 Categorising Geographic Relevance

There are several good reasons why continuous geographic relevance values should be categorised. The first reason is that the high precision of the values belies the actual inaccuracies that will be inherent in measuring distance and time with positioning sensors. The values imply computational and model accuracy not existing in reality. For example, if Object A is 1 meter more distant from a user than Object B, it could be said that Object B is more relevant than Object A, and the geographic relevance value may differ by 0.01 between the two objects. However, an information seeker would most likely perceive these two objects as being equally relevant. Also, a direct mapping of the values into visual variables would lead to perceptually indistinguishable map symbols. Additionally, categorising relevance data can increase the communication of relevance, with each category offering the opportunity to assign a label or symbolisation, and thereby express relevance using natural language terms or with map symbols. The aim of this section is to find how the categorisation process can operate on each relevance criterion. It addresses these problems following the main divisions shared by all spatio-temporal data – space, time, and attribute. To begin with the structure of the categories is discussed, followed by the categorisation of individual criteria of geographic relevance, and lastly by the categorisation method for overall values of geographic relevance. Once the geographic relevance values have been classified they can be applied in many different ways in order to support the efficient information seeking of relevant geographic information.

6.1.1 How should categories of relevance be structured?

This chapter describes how categories allow information seekers to drill down quickly, and move efficiently from an overview to the most relevant region(s) in a map display. The ability of an individual to carry out this task efficiently is greatly affected by the number of categories, and the number of objects within each of those categories. This is referred to in this chapter as the *structure* of the categories. The number of categories to output is a parameter found in most categorisation algorithms. It is worth considering this parameter, as the number of classes resulting from a categorisation of geographic relevance will have an influence on the subsequent interactions and cognitive processes of the information seeker. The cognitive processes are mainly affected by the structure of the categories in terms of the number of categories, but also the number of objects within each category. Four types of complexity are involved in categorising relevance-assessed data:

Decision Making – The structure of the categories will affect how many geographic information objects will need to be compared. Behavioural decision making theory states the complexity of a decision results from the number of alternatives to compare (Johnson and Payne 1985). For example, during an ideal information seeking process, the individual moves from a set of all geographic information objects to a small subset of highly relevant objects which can then be easily compared, and a decision arrived at. Categorisation that allocates many objects to the most relevant classes, and few to the least relevant classes will result in the individual finding it more difficult to narrow down the information search and having to compare more geographic information objects.

Visual Search – As with the decision making complexity, the structure of the categories will affect visual clutter. If the structure of the categories prevents effective drilling-down for the information seeker then forming a manageable subset of objects will be difficult, and therefore many map objects will remain which will most likely overlap and crowd the visible map space, which in turn leads to high visual complexity (Pombinho et al. 2009).

Interaction – More categories will most likely result in a greater complexity in handling the interaction with those categories. For example, if 10 categories are presented to a user as a list, and one must be chosen, then it is likely on a small screen that the list will need to be scrolled to discover and select the target category. With 4 categories the scrolling interaction is unlikely to be necessary. Agreement can be found for this in the work of Shneiderman (1996), who states that small numbers of categories appeal to users interacting with visual information.

Discrimination - Early research by Miller (1956) reviewed psychological studies and found that the ability to rate and discriminate between changes in various phenomena, such as sound or taste, could be categorised on average into 6.5 classes. Research that looked into the ability of individuals to rate and discriminate between documents based on their relevance has produced similar results (Rong et al. 1999). The number of categories has also been found to have an effect upon the ratings of relevance of documents during information seeking experiments. In the case of relevance judgements, one study showed that the number of rating classes on the scale affect the confidence of the ratings, and that overall seven classes allowed the participants to best represent their feelings regarding the relevance of the documents (Rong et al. 1999). Further evidence for this can be found in the experiments by Preston and Colman (2000), which compared scales from two to seven points in terms of their ability to discriminate, with individuals finding that between seven and ten categories offered the most discriminatory power, and also allowed the better reliability. In general, the common view is that the number of points on a rating scale must depend on the thing that is to be rated, if it easy to discriminate differences then more ratings are better than few (McKelvie 1978).

Based on the research discussed above, the approach in this chapter is to keep the number of categories lower than or equal to seven. The distribution of objects between these categories is then decided based on the type of relevance criterion being categorised, and will be addressed within the following two sections. The first section (6.1.2) looks into creating categories through spatial analysis of the relevance assessed dataset, and following this section 6.1.3 looks at categorisation of the dataset based on the relevance scores.

6.1.2 Classification of Space, Time and Topic

Classifying space is something that is carried out in language and cognition, as a way to generalise space in order for it to become easier to understand. A good example is the reference to a fiat or administrative spatial region (‘*some houses are in the nice area, others not*’) so that several objects can be differentiated rapidly. The characteristic used to differentiate the regions can draw upon all the various meanings of location that have been defined by (Edwardes 2007), from semantic to geometric. This section focuses on defining categorisation measures that produce a more qualitative communication of space, with the spatial analysis used to generate these categories working on the geometric and network representations of location held in a spatial database.

Direction

Categorising relevance datasets based on direction requires the definition of the categories used to communicate direction, and then a method by which to assign individual objects to those categories. The direction of objects from our location is commonly structured according to the embodied concept of AHEAD, LEFT, RIGHT and BEHIND (Tuan 1979, Franklin and Tversky 1990). Psychological experiments involving orientation have found that these four categories are equal to 0°, 90°, 180° and 270°, in correspondence to the bodily axis of an individual (Hintzman et al. 1981, Rieser 1989). The categories for this relevance criterion are then defined using these basic terms resulting in four categories. Assigning the relevance objects to each category requires the setting of thresholds. The thresholds defined represent a division of space into quadrants of equal size, one for each direction term (AHEAD, LEFT, RIGHT and BEHIND), as shown in Figure 31.

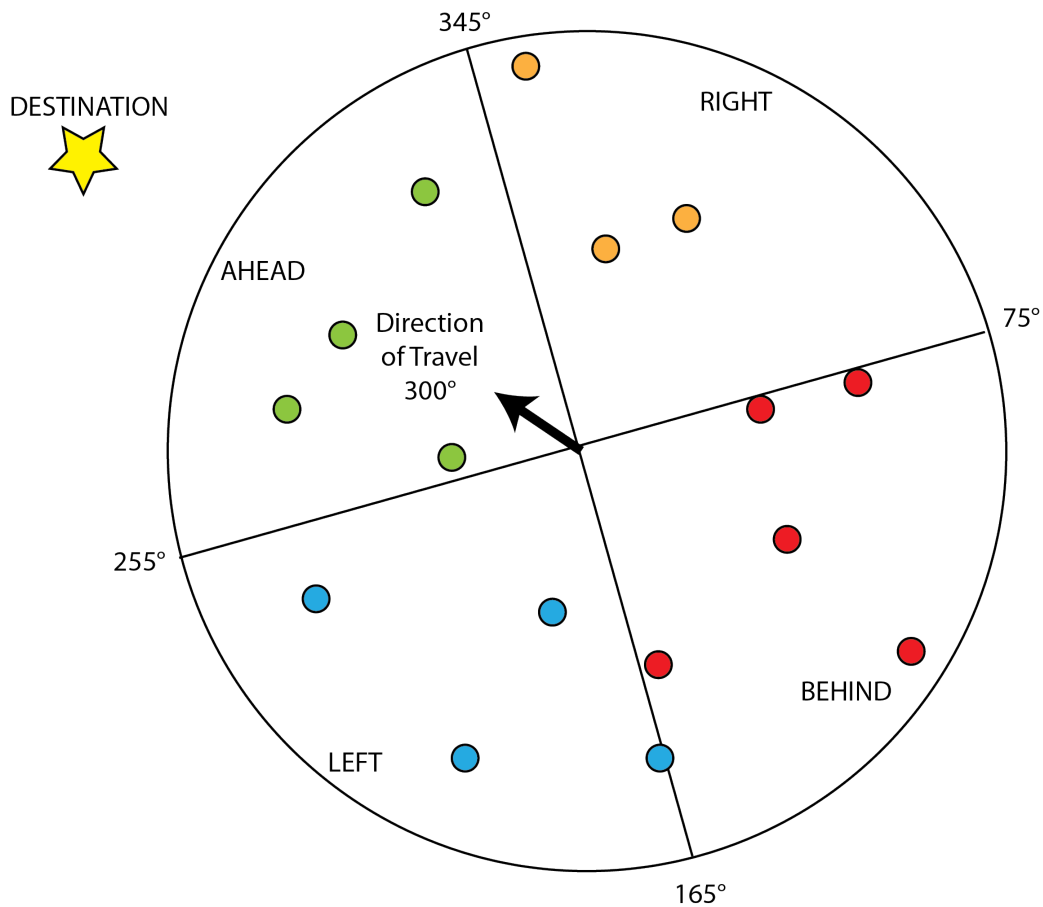


Figure 31 - Directional Categorisation - AHEAD=green, RIGHT=orange, LEFT=blue, BEHIND=red

It requires some contextual information, which is the angle between the current location and the planned destination and which is then used as the direction of travel (symbolised by *a* below). If the user is moving exactly to the North, then this value would be 0°. Also necessary is the calculation of the angles between the user and each object (symbolised as *o* below). The quadrant for AHEAD is then assigned to all objects where $o<(a\text{-}45°)$ and $o>(a+45°)$, RIGHT where $o>(a+45°)$ and $o<(a+135°)$, LEFT where $o<(a\text{-}45°)$ and $o>(a\text{-}135°)$ and BEHIND $o>(a+135°)$ and $o>(a\text{-}135°)$. Figure 31 shows an example of this categorisation for an individual with a heading of 300°.

Spatial and Spatio-Temporal Distance

Qualitative communication of distance can be carried out through the use of terms near or far. However, these terms require a great deal of contextual factors which cannot be easily inferred by a system (Hernández et al. 1995). Instead the categorisation method applied here uses discrete quantities of distance, as is less ambiguous and will therefore allow better judgements of what is relevant to the user. Referring to the distance of objects can be carried out through both references to physical distance, e.g. 100m metres away, or with reference to the amount of time it takes to travel over this distance, e.g. the car park is 5 minutes walk from here. As space is continuous, the precision of the distance measurements used as thresholds for each category and its labels is also considered important to the generation of categories. Using highly precise numbers, e.g. Category 1 - distance<128.46m, Category 2 distance<251.82m), will hinder the ability of the user to compare and make sense of the categories. This results from the heuristics used by individuals to compare numbers, and which result in inaccurate judgements of differences between extremely precise numbers (Thomas and Morwitz 2008). This is also not how distance is commonly communicated, with humans most likely preferring the lowest precision relevant to the scale of space being described. On the scale of geographic relevance assessments this would commonly be on a scale of tens (10m, 20m etc.) to hundreds of metres (100m, 200m etc). It could also give a false confidence in the accuracy of the user's location, used for calculating the distance values. The same consideration applies for space-time distances. However, a mode of travel must also be specified in this instance, as the time taken to travel over space varies with the travel speed. The categorisation process therefore takes each object, and calculates its spatial distance or spatio-temporal distance to the location of the user. An example categorisation of spatio-temporal distance is shown below in Figure 32, with the objects being divided into three classes for 5, 10 and 15 minute intervals.

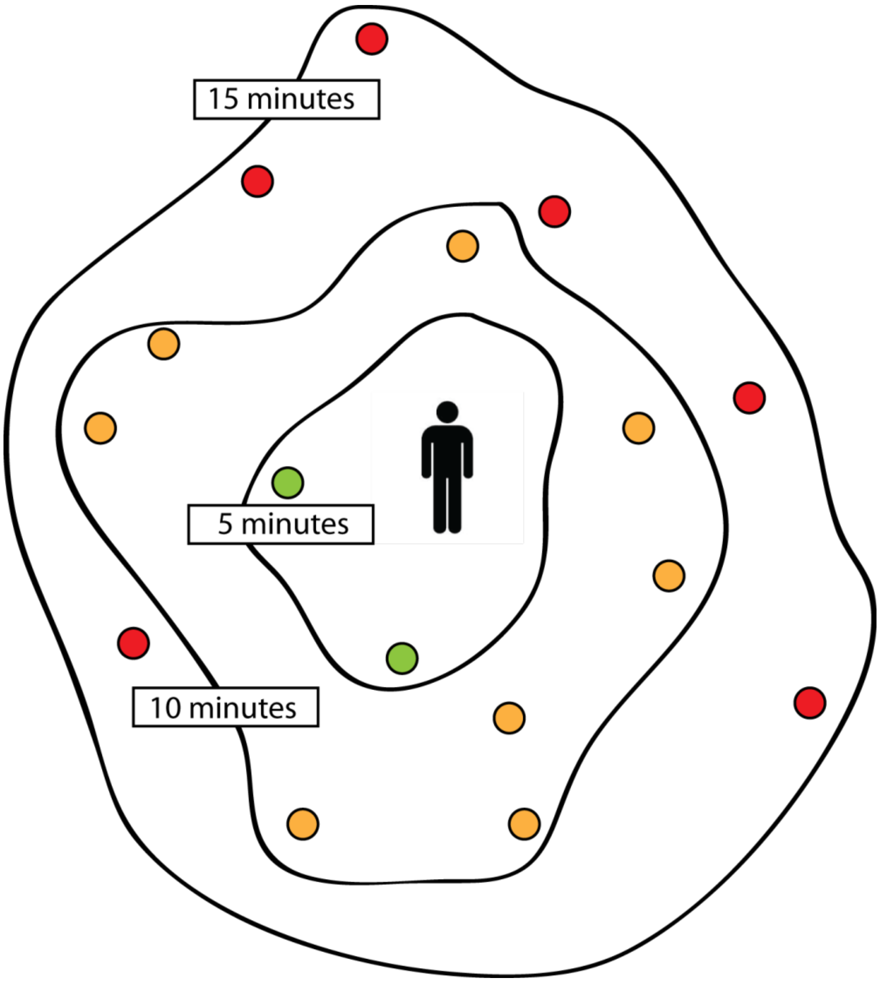


Figure 32 - Categorisation of space-time

The distances thresholds are specified using a quantile categorisation adapted to produce seven categories with rounded thresholds. For example, this rounding process would result in thresholds calculated as 14.357 minutes becoming 14 minutes, and the objects that are over this new rounded threshold are removed and entered into the next category.

Labelling these classes will then be carried out through the incorporation of the user context. If the information seeking is egocentric (based on the user's position) then the format of the label would be "<distance> m from current location". For searches based on the distance from a landmark, then the label format would be <distance> m from <landmark name>, e.g. 150m from railway station.

Clusters

Relevance assessments applied to the data, during an accompanying research project (see (De Sabbata 2013), assign each object to a cluster. However, if certain thresholds are not met then the clustering method records these objects as non-clustered. A basic categorisation is to create two classes of objects, those that belong to a cluster, and those that do not (Figure 33). This then later enables the user to include only clustered objects to narrow down their search.

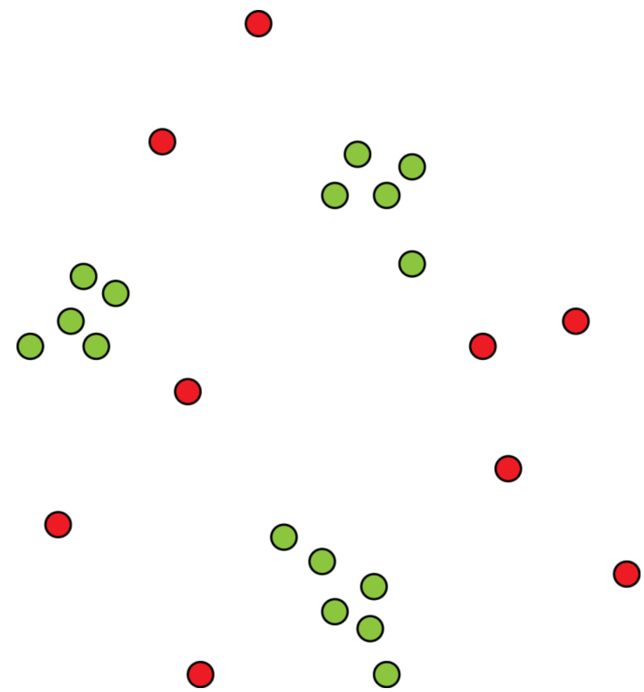


Figure 33 - Categorisation of clustered objects. Green=clustered, Red=not clustered

When labelling these clusters, it may be wise to avoid the term 'cluster' which is more common as a statistical or technical definition of data, and not commonly applied to the real world. The labelling of these features as clusters will therefore most likely not be familiar to naive users. More applicable is the term areas, as in sightseeing areas or nightlife areas. If labelling is necessary, then clusters would be better termed '<activity> areas', with the <activity> attached to the cluster class label coming from the context of activity at which the information seeking was targeted.

Co-Location

The distance from the geographic information objects to related objects offers many ways to classify the data. The most logical way is to allow a classification of the objects, based on a distance threshold. All objects that do not meet this threshold are put into a non co-located class, whilst the remaining objects are placed into a co-located class.

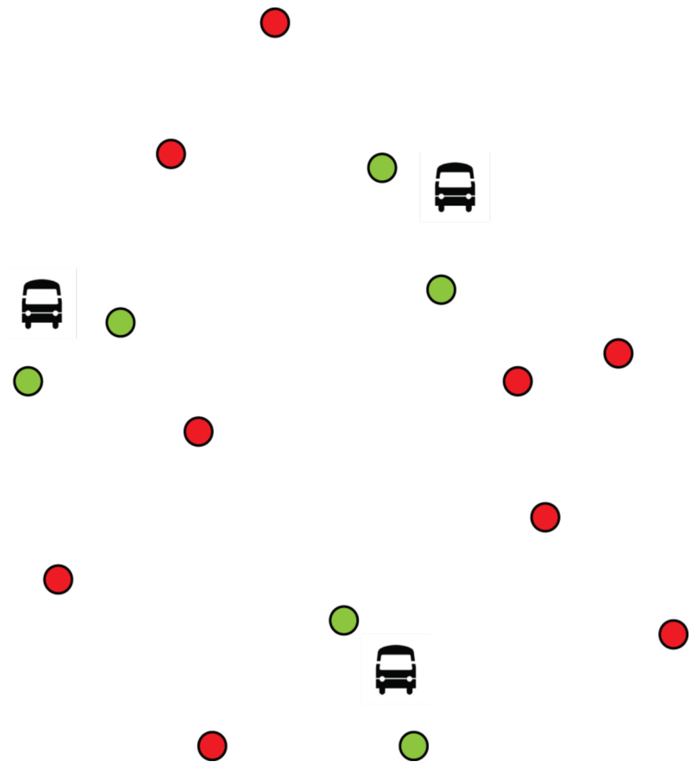


Figure 34 - Objects categorised according to the distance from a bus stop

A more sophisticated method would allow this to be carried out using the methodology described for spatial and spatio-temporal distance, where a classification is created from a discretisation of the distances into separate classes. The context required to do this is then the type of related object (e.g. bus stop). The labelling of the classes can follow that of the spatial distance categorisation, with the user location replaced with the object type e.g. Category1 = 50m from bus stop, Category2 = 50-100m from a bus stop.

Topicality

Whilst the four relevance criteria described above operate on input data from measurements that are continuous phenomena, such as space or time, topicality takes as input the object type assigned to each object (e.g. Restaurant, Shop). The method applied to categorise these data is to create a list of activities that mobile people might engage in and assign the raw category types to each activity that it could possibly afford, e.g. activity=eating -> category types=restaurant, cafe, bar, fast food, in order to produce a two tier hierarchy. The activity list was taken from a typology published by Reichenbacher et al. (2009). The categories for this relevance criterion are mutually exclusive as each object has only one category assigned to it, e.g. a restaurant cannot also be a bus stop.

6.1.3 Relevance Categorisation

This section focuses upon the classifications of continuous geographic relevance measurements held within the attribute data of the relevance-assessed datasets. The aim of the classification procedure is to support the decision making and information seeking of a user. Unlike with the categorisation demonstrated above, relevance is an abstract concept, and therefore has no inherent common meaning that can be used to label and assign objects to categories. In section 6.1.1 above, the aims of the classification are defined to support decision making, visual search, interaction and discrimination related to the relevance assessed objects. These aims result in two requirements for the categorisation method used.

The first requirement is that the classification should be able to produce highly relevant categories that contain a low number of member objects, so that the comparison of the most relevant objects does not become difficult, and the visual clutter is minimised. Additionally, the number of categories should not be greater than seven due to the complexity of interacting with many categories and discriminating between these categories. Traditional cartographic classification algorithms do not produce categories meeting these criteria, because they aim at visually communicating the underlying statistical distribution of a dataset as accurately as possible (Cromley and Mrozinski 1999, Galant 2006). When applied to relevance datasets, this can result in the most relevant categories containing large numbers of objects, if a large proportion of the objects contain high relevance values. The approach therefore taken is to utilise a form of quantile categorisation, which focuses on the number of objects within each category, instead of the statistical distribution of the relevance values. As the maximum number of categories utilised is limited to seven, a conventional quantile method could also result in large numbers of objects assigned to each category, e.g. 350 objects and seven categories will result in 50 objects per category. Therefore an exponential function is defined which assigns exponentially increasing numbers of objects as the ordinal relevance of the category decreases. This function then produces highly relevant categories that contain few objects. Furthermore, the exponent allows control over the categorisation process so that datasets containing large numbers of objects will result in the placement of few objects within the top category.

This function is defined below in equation (1), and calculates the number of objects (*numObj)* for a given class (c), where $\mathtt{C}^{\mathtt{p}}$ is the ordinal relevance of the category (e.g. most relevant category =1, 2nd most relevant category=2) raised to the power of an exponent $\mathtt{p}$ and divided by the summation of all these $\mathtt{C}^{\mathtt{p}}$ values for the total number of classes *n* and then multiplied by *t*.

$$numObj = \frac{C^p}{\sum_{i=0}^{n} C^p\,T} \qquad (1)$$

	Class Number	Number of Objects p=1	p=2	p=3
Most Relevant	1	25	5	1
	2	50	20	7
	3	75	45	24
	4	100	80	57
	5	125	125	112
	6	150	180	193
Least Relevant	7	175	245	306

Table 4 – Equation and output of a linear (p=1), squared (p=2) and cubic (p=3) categorisation of 700 objects

For example, if we have 700 objects and 7 classes the output of this function will be as shown above in Table 4, when the *p* parameter is equal to 1, 2, and 3. When p = 1, the output is a linear increase in the number of objects per category, but as the p parameter is increased the distribution of objects among the classes becomes exponential, with the higher relevant categories containing fewer objects and the less relevant categories more objects. Selecting the correct value for this parameter is important because, as shown above for *p*=3 in Table 4, it can result in the top category containing only one object. A solution to this is to specify a minimum desired number of objects in the top class, then iterate through gradually increasing *p* values until the desired number is reached for the top class, and then allow the categorisation to progress from that point with this value of *p*.

This method of classification was chosen as it generates highly relevant classes that contain few objects, and less relevant classes that contain larger amounts of objects. This means that the decision complexity of the most relevant classes is low as fewer objects must be compared. It also provides a good fit to the long tailed distributions that relevance models most often output (Fairthorne 2005, Stock 2006). Furthermore, this method allows the individual to quickly drill down to the most relevant objects. Additionally, it may also be possible for the relevance categorisation to be amended according to the context of the results returned. For example, higher p values can be used for larger result sets, and therefore keep the number of objects in the top categories at a constant number, regardless of the size of the result set returned. This will then have cognitive benefits as the amount of objects to be returned is kept at a constant number and will therefore support the information seeking and decision making that these datasets will support (Johnson and Payne 1985).

6.1.4 Applying categories to faceted classification

Faceted classification is an interaction framework that allows the categories (which are termed facets in this framework) of information objects to be utilised as a means to narrow down results sets during an information seeking process (Hearst 2008). Studies have shown that the faceted search framework is capable of improving the usability of an interface such that users can search through and break down large results sets in order to find and compare relevant documents and images (Hearst et al. 2002). Additionally, this interaction framework has been extended successfully to the development of mobile interfaces (Karlson et al. 2006) and geographic information retrieval (Frontiera 2008). This section describes how the categorisation processes described in sections 6.1.1 and 6.1.2 can be applied to the creation of such a framework, and how such a system might be designed. The aim of the system is to allow an individual to express complex information needs that encompass multiple dimensions of relevance.

The role of the categorisation is to first enumerate all possible categories for each relevance criterion. An information seeker can then select categories from each relevance criterion, with each selection gradually narrowing down the number of objects that are members of these selected categories. This movement can be conceptualised as a movement through a hierarchical structure (Perugini 2010). As shown in Figure 35 below, these hierarchies are created as the user selects categories from one facet after another, and selecting a category results in the creation of a path (see thick line in Figure 35). In this case the path represents a search for clusters that are within 15 minutes walk of the current location and not positioned behind the person's direction of travel.

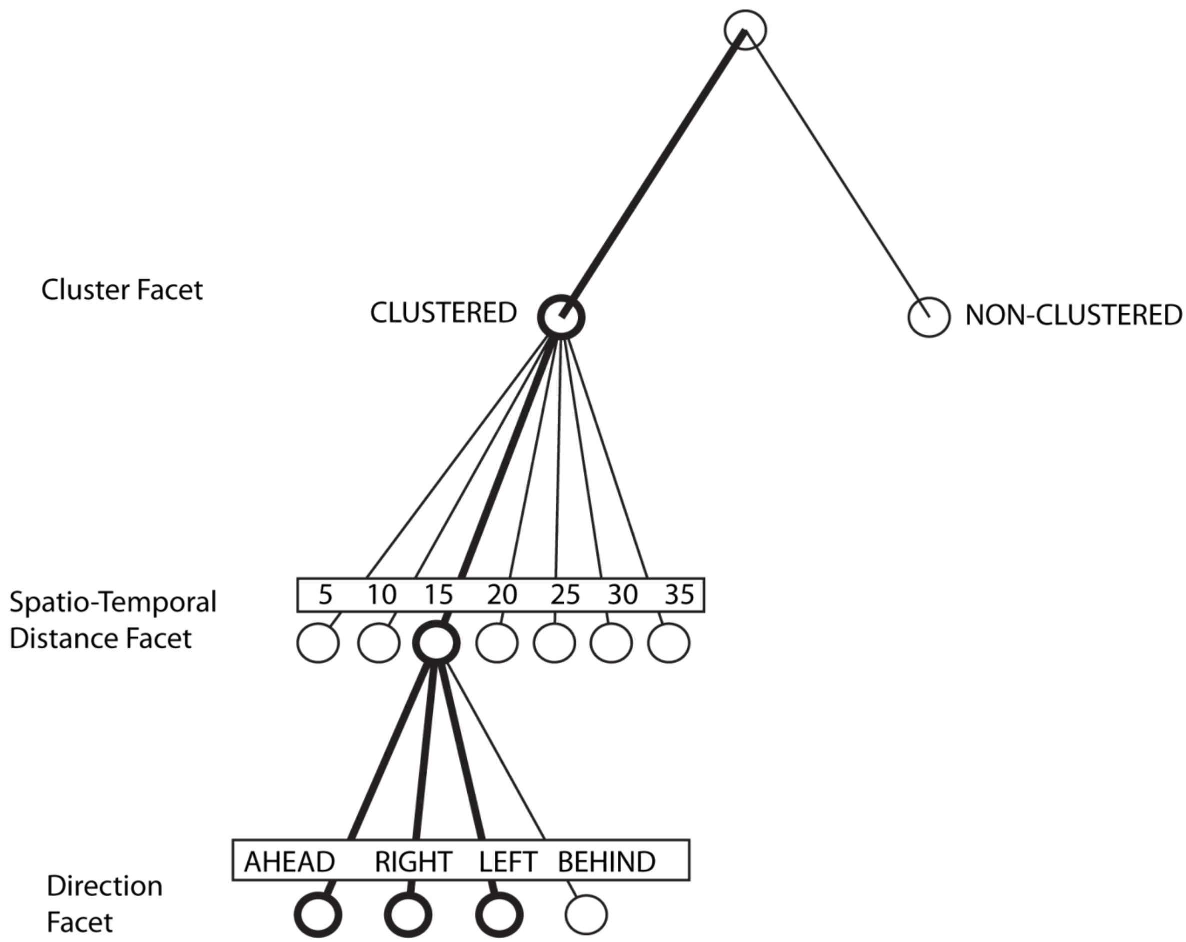


Figure 35 – Example hierarchy of facets for clustered object within 15 minutes and not behind

The end of this path relates to a subset of objects that meet all the criteria specified within this path. Important to note is that the order that these thresholds are applied in is irrelevant, as the resulting subset is always the same, but the intermediate stages will result in differing subsets.

To demonstrate the ideas discussed above, an example implementation was created that incorporated a faceted classifcation interface which used geographic relevance categorisations to produce the facets (Figure 36). In this implementation, the entire result set is used as input to the faceted classification. For mutually exclusive object categories, more than one category can be selected. For example, an individual can choose to show all cafes and restaurants. For mutually inclusive categories this is not possible, for example in Figure 37 - screenshot C, all the places within a 6 minute walk are selected, and therefore the categories that relate to a less than 6 minute walk time (<2, <3, <4 minutes) are also included. At each step the information is thresholded based on the categories selected, which results in each choice of category(s) from a facet producing a set of objects that meet the threshold, and a set that does not. The continual choice of facets results in the subsets becoming increasingly smaller, a map illustrating an example of this process is shown in Figure 36. Eventually the individual is left with a set of objects that meet all the desirable characteristics, i.e. needs expressed (shown in red on Figure 36) and the information seeking process can therefore focus on the comparison of these objects. With only a few facets applied to the result set, the result set become more manageable. In Figure 36 for instance, 1397 objects are reduced to 15 objects after the selection of only three facets. This represents a signifcant reduction in the visual complexity of the map and support for the decision maker due, to the low number of alternatives to consider.

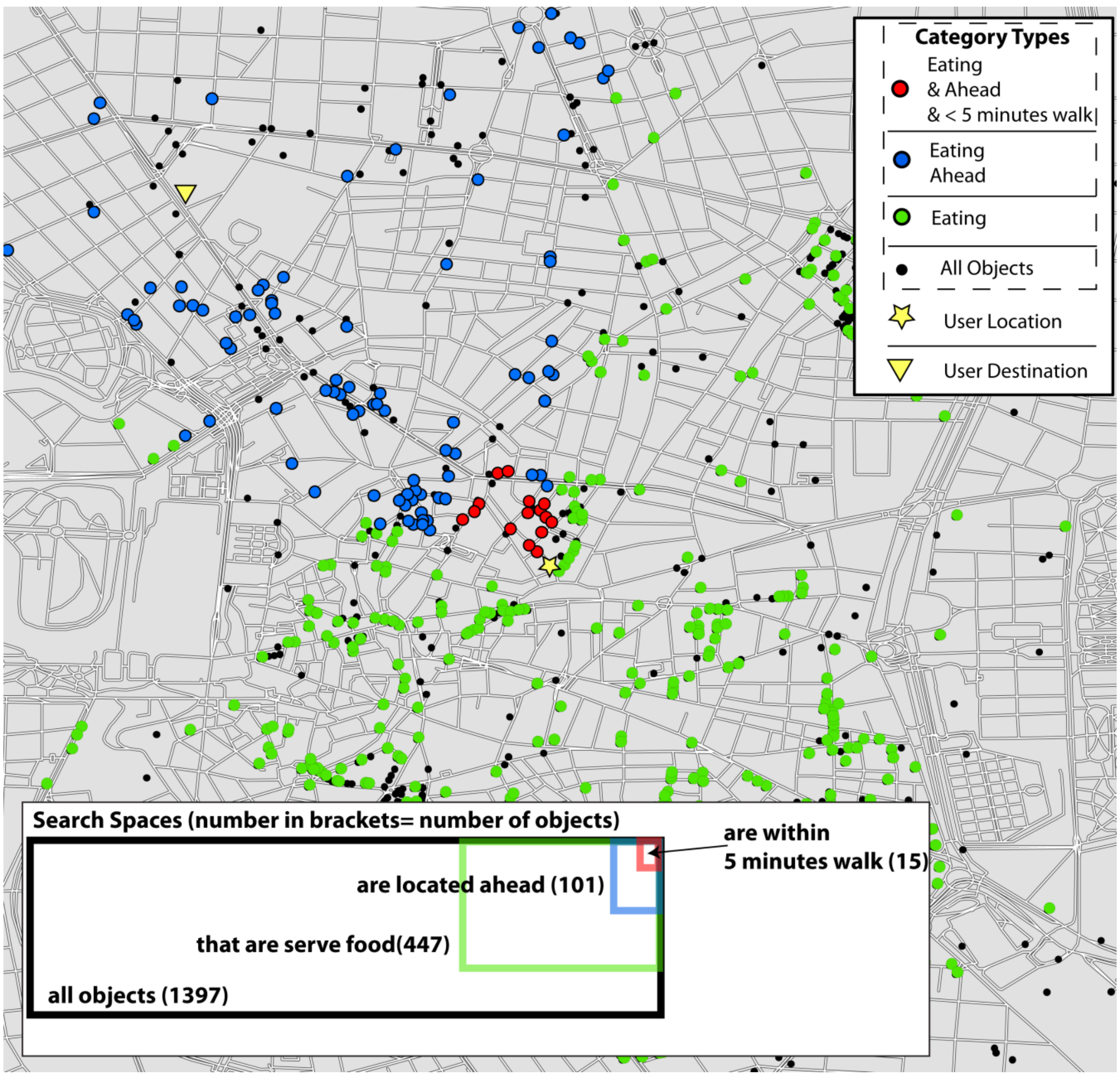


Figure 36 - Example of a faceted search output showing restaurants, located ahead of the user within a five minute walk (shown as red map symbols). Number in brackets = number of objects

Several options are possible when visually communicating this thresholding process, one can filter out those objects that are not within the subset specified by the user or apply a different

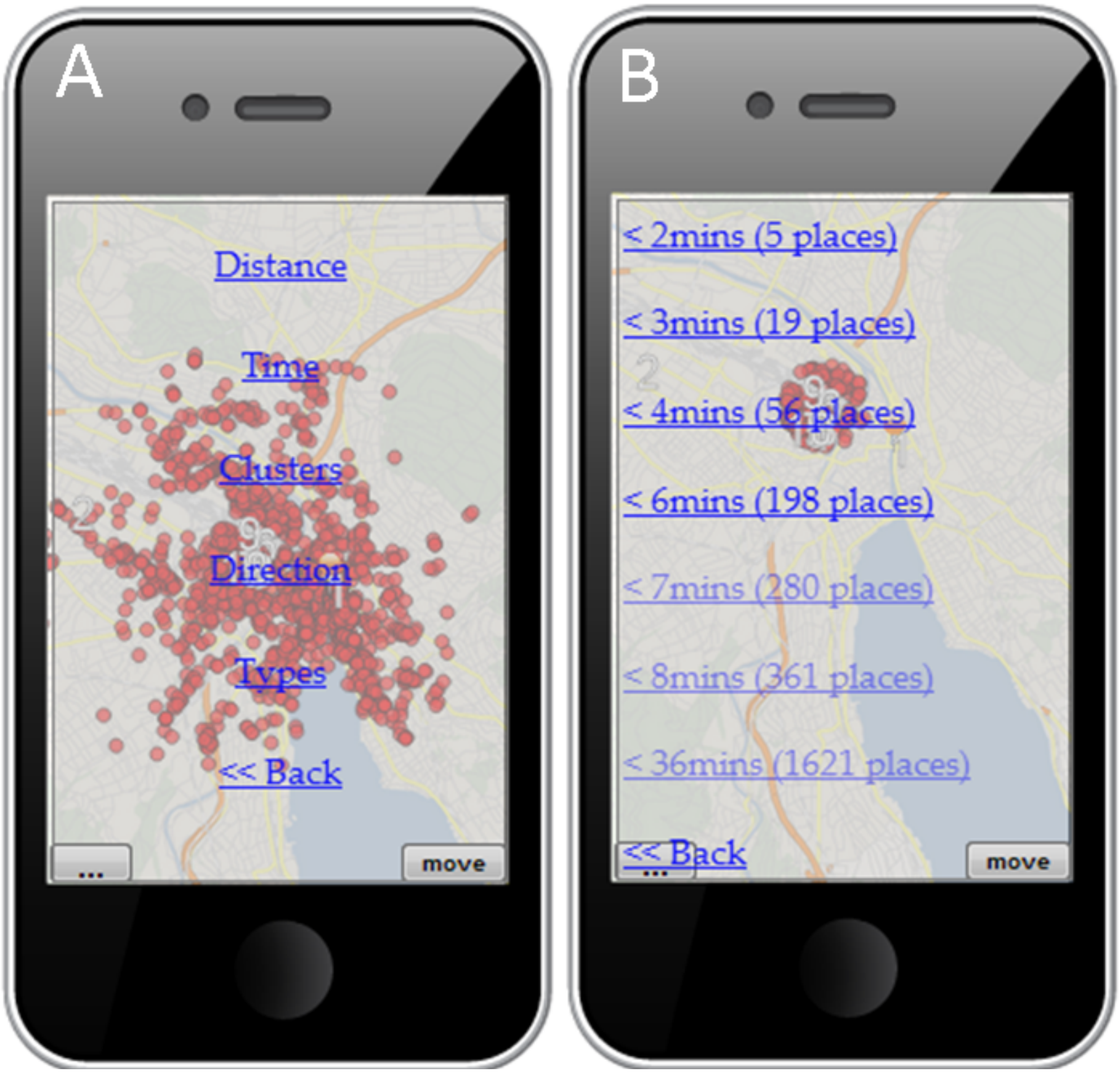


Figure 37 - Example faceted search interface. A=top level facets, B=spatio-temporal category facets (red objects meet the criteria, blue object do not)

symbology to each result set, as in Figure 37, or are simply between those objects that meet the criteria specified and those that do not. The latter approach is taken in the implementation described below, although all approaches are equally valid. The design of the interface is also complicated due to the small screen size, as the common method used for a full screen interface is to place the facets to the left or right of the screen. This method has the advantage of allowing the interactions with the facets to become instantly visible, an advantage of which is to communicate the changes in the size of the set of results that fit to the facets being chosen. A translucent menu was used, to enable the facets to be placed over the whole of the screen and therefore be visible and large enough to interact with. Furthermore, the map is kept visible in the background and therefore the interactions with the facets still remains visible to the information seeker. An example of this can be seen in Figure 37 – screenshot B. Another important factor of faceted search suggested by Hearst (2008), i.e. the number of objects that are contained within each facet (shown in brackets after each label). This number plays two roles. First, to guide the user to understand the effect of choosing a category. Second, to remove the possiblity that the information seeker ends up with a subset containing no objects.

6.2 Metaphors of Geographic Relevance

Metaphors are commonly used to enhance the communication of an abstract concept, of which geographic relevance is an excellent example. In this section metaphors are applied to the linguistic and visual communication along with the design of interaction methods. The basic structure of a metaphor is formed by linking two concepts, a source to a target concept. The use of a metaphor is to take an unfamiliar (target) concept and describe it using a familiar (source) concept. The source-target mapping is therefore uni-directional. Lakoff (1983) provides an example a metaphor with "IDEAS ARE FOOD" (e.g. half-baked ideas). This mapping communicates to the interpreter not the literal meaning that ideas actually are food, but that the concept of an IDEA operates in a similar way to the concept of FOOD. For example, saying something is highly relevant means mapping the degree of relevance to the concept of height. Applying this to geographic relevance begins with the need to define the target domain. The approach taken here is a practical one. It is not necessary to describe in any great detail the semantics of geographic relevance, but rather to delineate the underlying features that an information seeker would need to understand about geographic relevance in order for it to become useful. Figure 38 schematically shows the position of five relevance-assessed objects (A,B,C,D and E), on a relevance scale from 0 to 1 (shown at the bottom of Figure 38). The relevance scale has also been categorised into three relevance categories. With this structure the relevance of the objects can be communicated to various degrees of precision as described below:

Binary level of precision - The most basic and necessary message conveyed by a metaphor of relevance is that some objects are relevant, whilst others are irrelevant. This is the least precise communication, representing data at a nominal level of measurement.

Categorical level of precision - A more precise communication would be to express the difference between the relevance of objects by allowing the membership of relevance categories to be perceived. For example, Object A is in relevance category 1 (most relevant category) and Object B is in relevance category 2 (second most relevant category) and therefore one can communicate the difference between two categories of geographic relevance. As these categories can be ordered by relevance, the level of measurement for this level of precision is as on an ordinal level of measurement. However its precision is lessened, as several objects can belong to the same category. This result in the communication of rank being vaguer than for the rank level of precision described below.

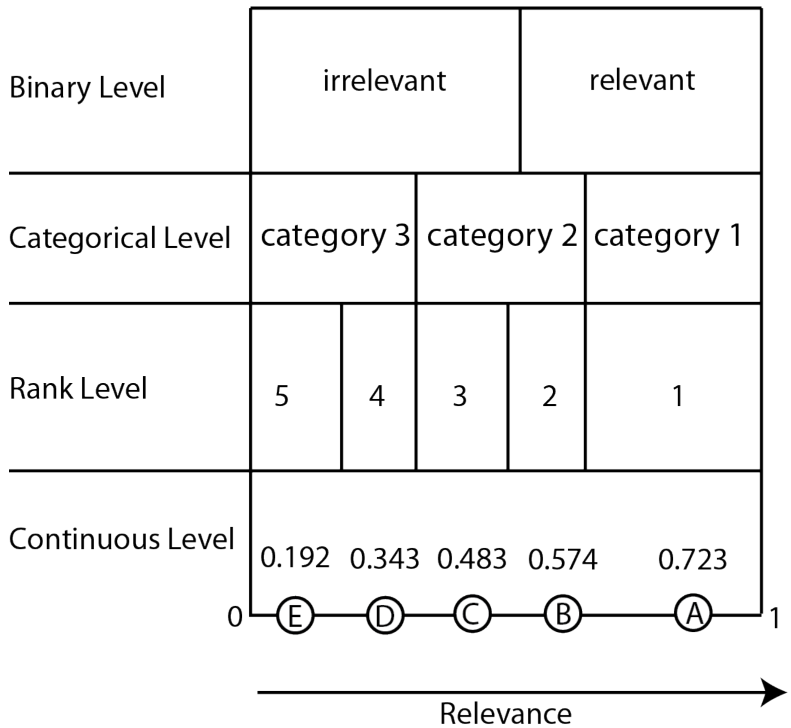


Figure 38 – Example visual schematic of two relevance assessed objects

Rank Level of Precision – This level of precision allows comparison of the object based on the rank, but removes the ability to see the relative difference in relevance between objects. For example, it is impossible to know that Object A (relevance=.723) is twice as relevant as Object D (relevance=.343).

Continuous level of precision - The most specific approach would be to express the difference between the two objects as a continuous value, on a ratio level of measurement. An example would be to communicate that Object A is twice as relevant as Object D. As shown in future sections, this method is only applicable during the application of visual metaphors.

These four levels of precision represent four different ways in which the relevance target domain can be communicated. This will therefore have an effect upon the choice of which source domain will offer the best structural mapping to the target domain. The required precision will most likely be derived from the context to which the metaphor is applied and the means (visual or linguistic) used to communicate relevance. For example, common linguistic metaphorical expressions of relevance (see next section) do not express relevance as a continuous concept. The method of metaphorical communication therefore places limitations upon the level of precision that can be communicated to a user. The following sections go on to describe both linguistic and visual metaphors of relevance that utilise the levels of precision described in this section.

6.3 Linguistic Expressions of Relevance

Several different ways of describing the degree of relevance of something can be found, from 'wholly relevant' or 'strongly relevant' to 'closely relevant' (Carlier et al. 2000, Spink et al. 1998, Saracevic et al. 1997, Lakoff 1973). The examples in the last sentence use the metaphors of wholeness, height and distance to communicate the degree of relevance. There is a simple reason that these concepts clearly communicate the degree of relevance, it is because they are linked to our embodied experience. Furthermore, this embodied experience has allowed us to develop a single concept that lies behind the understanding of both strength and height (Lakoff 1990). This concept is termed SCALE, and is a member of a set of such concepts referred to as image schema world (Lakoff and Johnson 1980). Image schemas are cognitive structures developed through our embodied interaction with our perceived environment (Kuhn 1993). SCALE is a member concept of the spatial group of image schemas, and refers to an increase or decrease in a metaphorical amount and fits extremely well to the description of geographic relevance in the preceding section (Grady 2005). It is therefore used as the conceptual basis to develop mappings between the target domain of relevance and a source domain.

The image schema SCALE can be expressed in several different ways. From the perspective of linguistic metaphors, a common method is the application of antonyms, as in weakly or strongly relevant. This is because there is a strong semantic link between the SCALE image schema and gradations of quantity expressed as antonyms (Popova 2005). Analysis of antonyms has shown that several different types of antonyms exist and therefore the communication of the SCALE concept will be affected by the type of antonym chosen (Evans and Green 2006). Perhaps the closest type of antonym to the actual characteristics of relevance is known as the monoscalar. This type of polar antonym extends from the quantity of zero in a positive direction. An example of this is the concept of SHORT–LONG. One term is associated with a higher value of the property LENGTH, and the other term with a lower value of that property. The other type of antonym is known as biscalar, and can be further divided into two types, equipollent and parallel. Equipollent antonyms arrange themselves as symmetrically opposite; both begin at zero but increase in opposite directions. A good example of this is the HOT–COLD concept. It has been proposed that this type of antonym stems from the mechanism of sensation, as water at the same temperature as the body provokes little sensation, but colder or warmer water will provoke sensations that are different from one another, but still related to the temperature of the water (Evans and Green 2006). Parallel types are similar to equipollent, but one term goes towards zero and the other towards positive infinity, both partly overlapping. An example for this is the HARD–SOFT concept. The most common of these antonym types is the monoscalar.

A second common linguistic method to describe the quantities of something is through the application of linguistic hedges, the common way in which the image schema of SCALE is expressed (Johnson 1987, Grady 2005, Clausner and Croft 1999). These hedges, such as *very*, *less*, or *more*, are usually adjectives that can be applied to communicate uncertainty or expectations of something and are also commonly used within the fuzzy set theory proposed by Zadeh (1965) to label each set. They are also applied to communicate the degree of relevance in everyday speech, through the use of very relevant or less relevant. Linguistic hedges are therefore included within the analysis of linguistic communications of degrees of relevance.

6.3.1 Analysis of Metaphor and Hedge use

To linguistically analyse the description of relevance, a list of terms was taken from sources that looked at the communication or the judgement of relevance. Table 5 below displays the terms

Source Domain	**Example**	**Reference**

Temperature	*Hotly Relevant*	(Reichenbacher 2005b)
Height	*Highly Relevant*	(Spink et al. 1998)
Strength	*Strongly Relevant*	(Kohavi and John 1997)
Fullness	*Fully Relevant*	(Huiskes and Lew 2008)
Size	*Greatly Relevant*	(Trieschnigg et al. 2009)
Distance	*Closely Relevant*	(Carlier et al. 2000)
Wholeness	*Wholly Relevant*	(Ogawa et al. 1991)
Hedge	*Quite Relevant*	(Saracevic et al. 1997)

Table 5 - Terms used for the study, along with references containing their use

utilised in this section. They come mostly from studies that focus on relevance of quantity of relevance, as other metaphorical terms exist that express the uncertainty of relevance, e.g. clarity can be used to communicate uncertainty as in '*this is clearly relevant*', and do not communicate quantity. The review of literature resulted in a list of seven metaphorical antonyms used. Additionally, hedges were also taken into account in this study, resulting in a total of eight possible ways of describing relevance, with most of the content made up from monoscalar antonyms, the exception being the TEMPERATURE metaphor (Figure 39). The other exception is that DISTANCE, which is inverted in respect to the others; a decreasing distance is equal to an increasing quantity of relevance.

The aim of the analysis of these terms is to discover which of these source domain concepts are the most often used when communicating degrees of relevance. The analysis was carried out by performing searches on Google and Twitter in order to gauge the commonality of use. Both Google and Twitter searches were carried out with each term entered in quotation marks to allow only that exact term to be used as the query term e.g. "quite relevant". All the terms included during this query process can be found in Appendix 1, and reflect all the possible terms that can be associated with each metaphor or hedge. The listed terms encompass both the adjective (relevant) and noun (relevance) form of relevance. Both Google and Twitter were queried on 15.02.2012. Google was queried once, but Tweets were collected every hour during the whole of that day to ensure time zones did not have an effect on the results. The number of Google 'hits' was collected for queries using every term and collated into a spreadsheet. Twitter results were collected in an automated way using Google Docs and an augmented script provided by (Hawksey 2012). This script allowed the place name or xy coordinates (if available) of each tweet to be extracted into a spreadsheet, along with the text content of the tweet. Although a limit of 1500 tweets per query exists in Twitter, this limit was not reached.

The metaphor group and linguistic hedge group allowed different numbers of gradations to be expressed, for example the hedge group contains the most different terms (13) whilst the HEIGHT group contains the least different terms (3). Therefore, during the analysis of Google results, the top three terms were taken from all of the groups to ensure the comparison was equal. These results for these top three terms were then summated to give a total number of web documents containing these search terms. As shown in Figure 40, the results show large differences between each term group for the number of resulting documents including these terms. Both HEDGE and HEIGHT could be seen as members of a top grouping. HEDGE came out as the most commonly used means to express the degree of relevance with over 155 million web documents containing one of the top three search terms for this HEDGE group. HEIGHT followed as second with 92 million web documents. The next groups with around 100,000

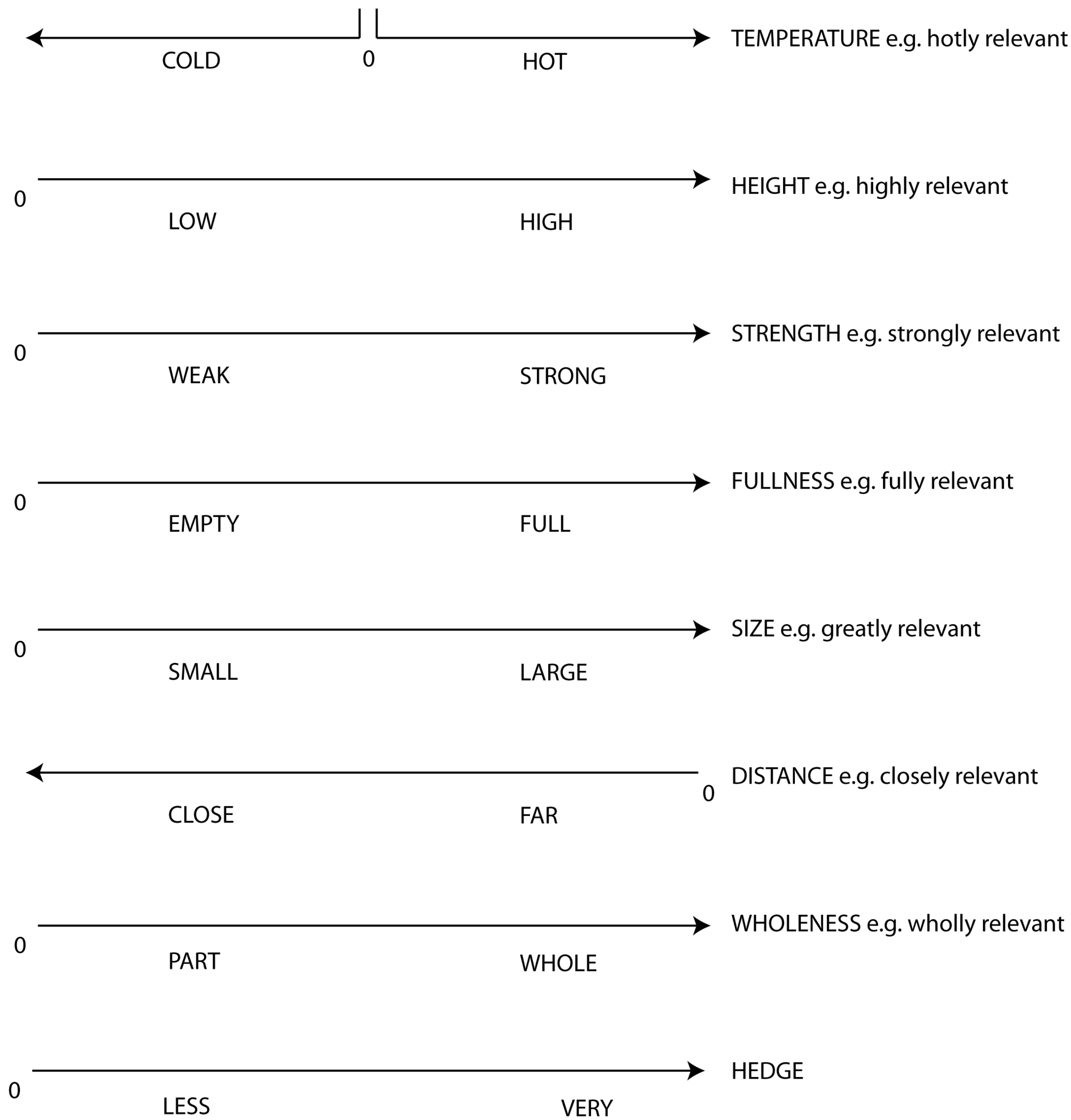


Figure 39 - Linguistic metaphors and Hedges used to communicate relevance

results are SIZE, STRENGTH, FULLNESS, WHOLENESS, and DISTANCE. The least common is the TEMPERATURE antonym with only 56600 web documents containing a term from this group.

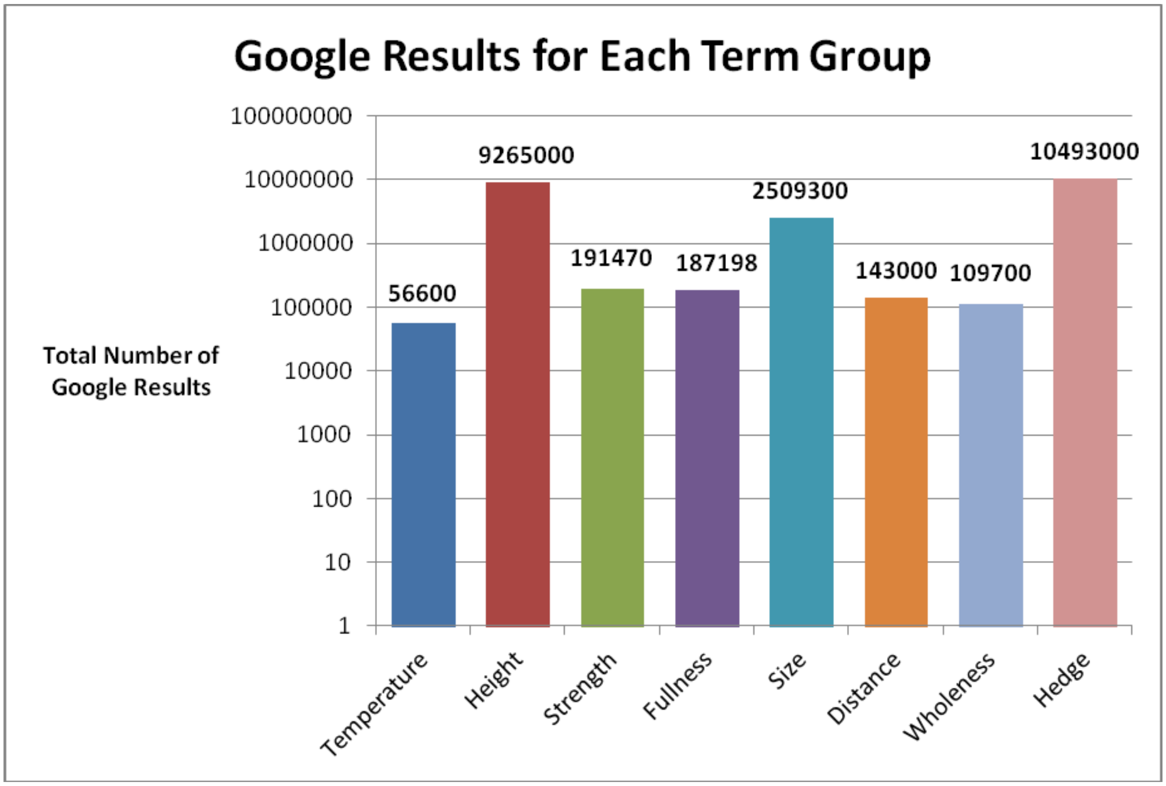


Figure 40 - Results of Google results returned for each metaphor and the hedge group

A common behaviour of Twitter users is to forward on tweets that they find interesting or useful for their followers; these forwarded messages are known as re-tweets. Including these re-tweets will result in an overestimation of the number of tweets containing the relevance terms, and therefore all re-tweets were filtered from the dataset. Additionally, only the top three terms from those term groups that contained more than three terms were counted in order to normalise the count statistics.

In total, after the filtering, 2111 tweets were collected that communicated the relevance of something. Overall analysis of the term frequency showed a similar distribution to the Google analysis results. As with the Google result analysis, the hedge term group was the most popular although to a more significant degree, as the second most popular, HEIGHT, returned three times fewer results. Perhaps the biggest difference between Google and Twitter was with the TEMPERATURE group, which returned no results for any of its member terms.

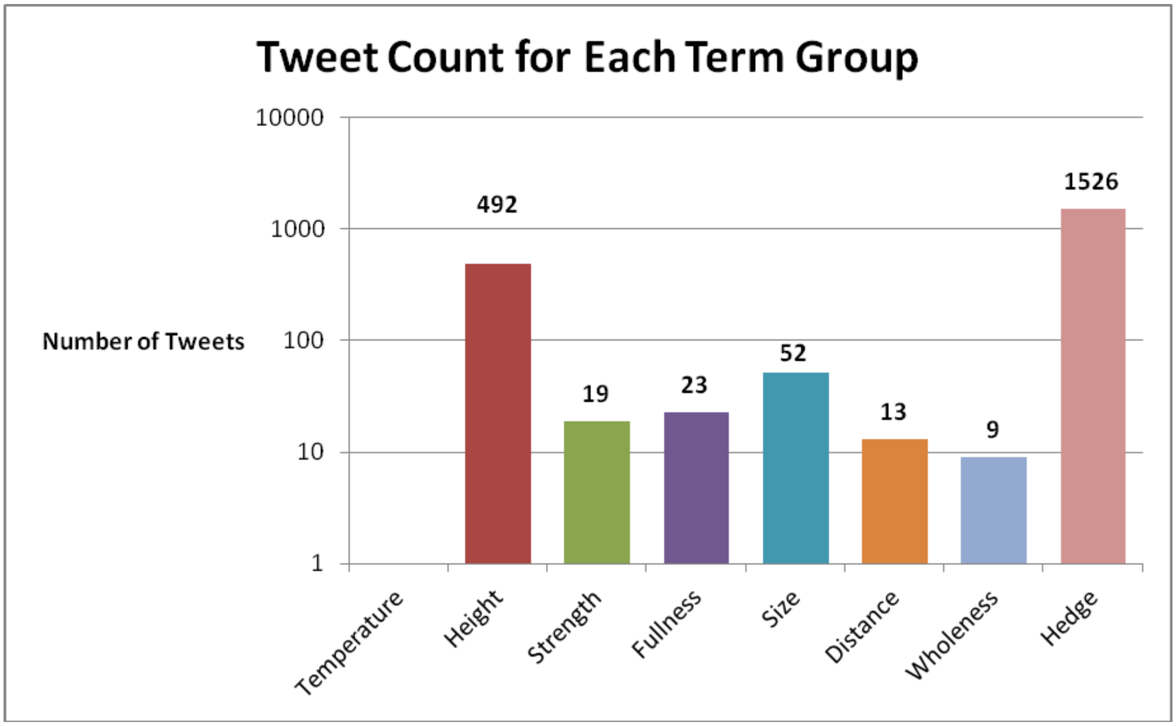


Figure 41 - Twitter results returned for each metaphor and hedge group

The results provide evidence that HEDGE terms are most commonly used to describe degrees of relevance, at least within the data sources included in this analysis. This commonality can be found in the frequency with which they are used. An explanation for this finding could be that HEDGE terms are more expressive, in that the speaker is able to express a greater number of differing degrees of relevance than with the antonyms used during metaphor use. It is also likely that hedging in general is a more common means of communicating quantity than metaphor use, and therefore will most often be found when communicating quantity for many other concepts aside from relevance. Further evidence for the popularity of the terms is that the separate two sources of Google and Twitter show a high amount of correlation. When the results of the two sources were ranked, only the strength and fullness categories differed in their ranked location and therefore the high level of agreement suggests that these results hold some validity beyond the information sources used.

The purpose of this section was to discover which linguistic metaphors are employed to commonly communicate relevance. This has significance for the linguistic communication of geographic relevance, which could be carried out through labelling on a graphical interface, or even employed as verbal commands. Equally important is the visual communication of geographic relevance through the use of metaphors, and this is dealt with in the next section.

6.4 Visual Metaphors

As geographic relevance is a concept that can be communicated by visual representations of space, it is also necessary to investigate how metaphors can be used to encode relevance within map symbols. A similar approach is used as with linguistic metaphors, to define a mapping that takes concepts from everyday experience, and apply them to the target domain of relevance. The mapping between source and target domain for the visual metaphors of geographic relevance draws on work carried out in the field of linguistics and cognitive science, in the proposal of theories of image schemas and basic domains first proposed by Lakoff and Johnson (1980) and Langacker (1986). Both theories share similarities, in that they relate directly to sensory and perceptual experience. Basic domains include such concepts as TEMPERATURE and COLOUR, and differ to image schemas in that they can be derived from subjective experience, including concepts which are not imagistic (Evans and Green 2006). A good example of such a basic domain is TIME, which is subjectively experienced, and not experienced directly by sensory organs. These two theories have one significant benefit to the derivation of a source domain, they are derived from experience and concepts that are shared by the majority of individuals (Clausner and Croft 1999). This allows the concepts to be recognised by users from a range of backgrounds and cultures.

The metaphors proposed fall into one of ten groups, and come from proposed lists of both image schemas (Risch 2008) and basic domains (Evans and Green 2006, Clausner and Croft 1999). These lists are the foundation for the design of metaphors for geographic relevance based on experiential concepts. In compiling the list, both image schema and basic domains contained concepts that were either too general (e.g. basic domains contain the concepts of SPACE and TIME) or difficult to visualise in a non-abstract way (e.g. the image schema ATTRACTION) and therefore were not included. Furthermore, it was important that the concepts drawn from these two sources did not overlap, and that they possessed a structure that could be related to one of the levels of precision described above in section 6.2. In general, the conceptual structures listed are monoscalar or biscalar, similar to that of the one described above for linguistic metaphors. After consideration of these structure and applicability to relevance, three concepts were taken from the basic domains (TEMPERATURE, COLOUR, EMOTION), whilst seven concepts from image schema (SCALE, HIGH LOW, UPDOWN, FULL EMPTY, CONTAINMENT, MOTION, CONTAINER). Visual metaphors were then created that fit within these concepts to demonstrate how the concepts can be implemented to symbolise relevance. The metaphors included within these groups do not represent an exhaustive list, but merely visually demonstrate how these concepts can be used to influence the design of map symbologies that aim to communicate relevance.

Several important points about these source domains should be noted. The first point is that some domains are limited in the levels of precision that they can support. As discussed in section 6.2, four levels of precision exist and not all concepts are able to communicate all four of these levels. The majority of these concepts can be communicated through a metaphor that has a continuous structure, such as heat, light, or height. However, the CONTAINER concept is not able to include these continuous metaphors, as it is fundamentally discrete. The most precise it could possibly be is to communicate the categorical level of precision, as CONTAINMENT at an abstract level; this concept is a discrete topological relationship (in or out) and therefore requires discrete 'containers'.

A second point worth highlighting concerns the development of the visual design from the original concept. Designing the symbols for the metaphors will play an important role in the ability of the individuals to recognise the meaning encoded within the visual metaphor. A well designed map symbol will help a user to recognise exactly what is being communicated and therefore the structure of the source domain within the concept, which can then be mapped to the target domain. The symbology used for the visual metaphors can range from the non-abstract mimetic (pictorial) to the abstract arbitrary (geometric objects) as defined by MacEachren (1995). An example of this can be seen in the TEMPERATURE metaphor in Figure 42, with red to blue objects (arbitrary) to the more mimetic thermometers symbols. All the metaphors can be built with both symbology types, although the arbitrary symbologies need to be communicated with two different methods for image schema and basic domains. For image schemas the arbitrary symbologies (usually shown on the left hand side of each metaphor type in Fig. 42), for example HIGH-LOW requires the spatial configuration of two objects. One object represents the 'ground' and the other object is placed relative to this 'ground' object to communicate height.

For the basic domains, visual variables are employed to communicate the metaphor type (hot=red, cold=blue). The metaphorical use of visual variables differs from the semiotic application, as it requires that the individual is not able to relate the change in colour directly to a quantity of relevance, but instead to an emotion or feeling, such as heat. The mapping to relevance must then take place once the link to the underlying concept has been established. The exception for this is the EMOTION group, which is difficult to communicate using the mimetic symbologies due to the way in which they communicate. The EMOTION group communicates quantities using a similar mechanism to that used by the Chernoff face, as described by (Chernoff 1973), which operates because recognition of the facial features is critical if the EMOTION of the face is to be decoded.

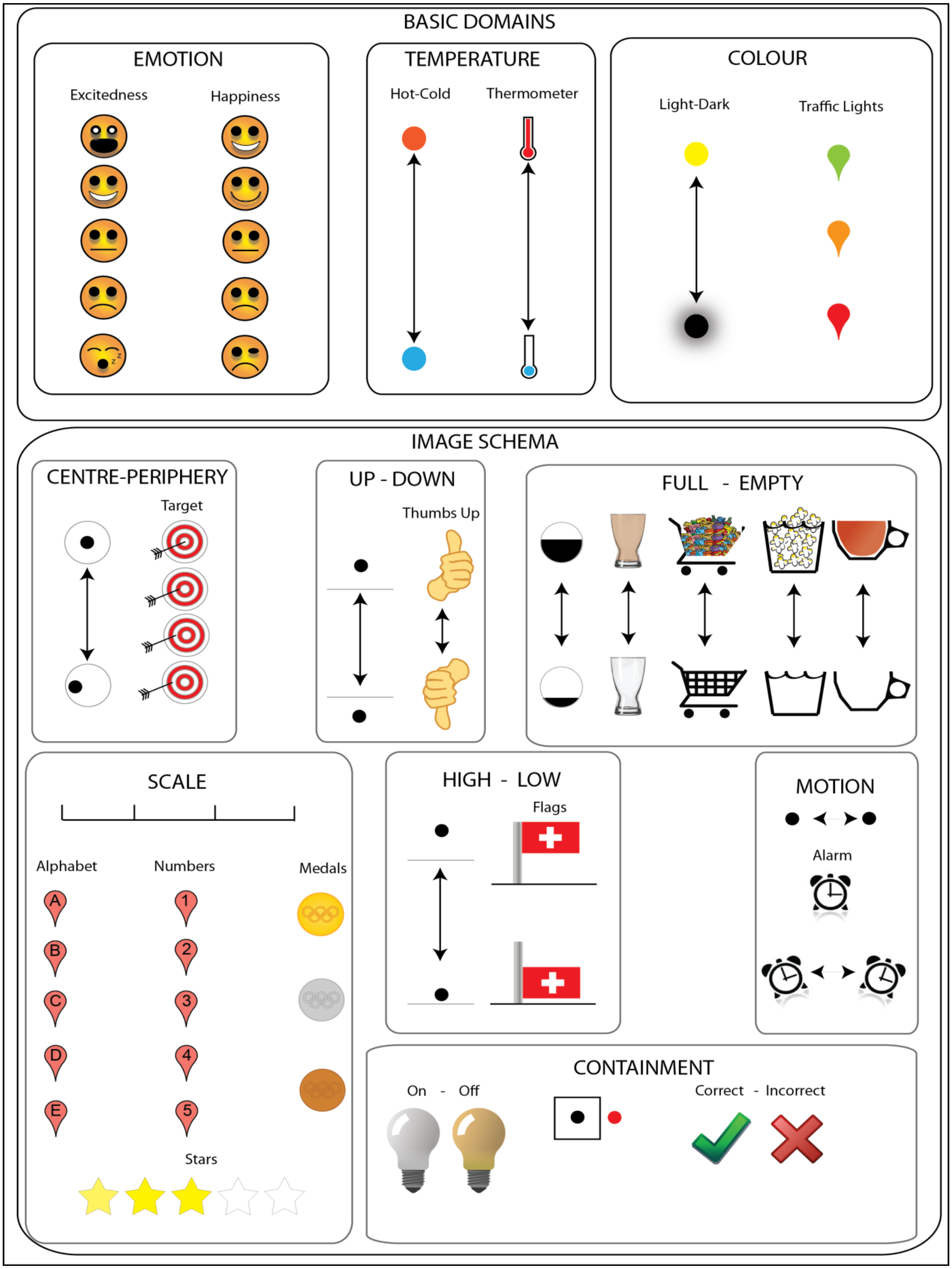


Figure 42 - Visual Metaphors of Geographic Relevance

Which metaphor is applicable to the representation of geographic relevance will be dependent upon how the relevance is represented and the characteristics of the object or its environment that contribute to its relevance. Some contextual characteristics that may dictate the applicability of a given metaphor are described below:

Binary, Continuous or Discrete - An important criterion is whether the property is continuous, discrete, or binary. For example, CONTAINMENT is a good example of a metaphor that can communicate with binary states. An example would be if the geographic relevance of a shop consisted only of being in a state of open or closed. However, in practice a single binary relevant property is rarely the case, and metaphors that communicate categorical, rank or continuous levels of precision are likely to be more applicable. Furthermore, metaphors that can communicate the highest level of precision will also be more flexible as they can be scaled down to represent the lower levels of precision. An example would be taking the FULL-EMPTY concept and visualising at a binary level of precision, e.g. full or empty.

Levels of Measurement – Although geographic relevance is a ratio level of measurement, this can easily be converted to an ordinal level by ranking the result set by relevance scores. SCALE offers a common way to visualise such rankings, examples of this can be seen with Google Maps using the alphabet A, B, C … (see Fig. 42). An important consideration is to find a way to represent the scale that does not result in confusion as to the direction of the scale. For example ten objects labelled with numbers from 1 to 10 to represent the relevance rank could be interpreted as a rank, 1 is equal to 1^{st} , or conversely as a quantity, i.e. 10 is greater than 1, so 10 is perceived as the most relevant.

Context of interpretation – The surrounding context of the information seeker will most likely have an effect on the interpretation of a metaphor. For example, when assessing the relevance of places for a nightlife activity, the hot (relevant)-cold (irrelevant) metaphor may make sense. When seeking a good ski run, this metaphor would begin to make less sense to an information seeker. It is likely that this consideration would have to be made at a design level, through analysis of the activities that a particular implementation would support and the properties that make up the relevance of the information.

Finally, to judge the applicability of the visual metaphors discussed above, an important step is an empirical evaluation to discover if their meanings are easily decoded. The evaluation of a selection of these metaphors is carried out in chapter 7.

6.5 Interaction Metaphor for Relevance Zooming

The visual and linguistic metaphors of relevance were applied to the communication of relevance, but methods to enrich the interactions with relevance assessed datasets are also necessary to consider. This section deals with the description of a metaphor which can help with the process of seeking information, and how it can be implemented in a working system. A metaphor based around common map controls termed Relevance Zooming is discussed. First the source domain of zooming is discussed and the common map interface tools that allow zooming are reviewed. Following from this, an exploration of how the process of zooming might affect the target domain is explored before an implementation of that utilises these target domains is demonstrated.

6.5.1 Zooming as a source domain

The source domain for relevance zooming is the interaction commonly referred to as zooming. This interaction has different meanings in different domains, and therefore it is necessary to first define what it means in the context of relevance. Although zooming has been thought of being analogous to the common action performed by optical cameras, Jackson (1990) argues that a more sensible grounding is not simply with the change of view, but also how it affects the cognitive processes of individuals by allowing someone to 'focus' on something. Furthermore, alteration to the extents of a space being viewed is not the only application of zooming. The zooming interaction can enable the exploration through the three main elements of spatial data, space, time and attribute.

Zooming in space is most typically implemented as a means to alter the map scale, and is a feature of most GI systems and web mapping services. Closely linked to the zooming of map scale is a type of zooming that alters the level of detail of information contained within the map view, referred to as semantic zooming by Harrower & Sheesley (2005) or content zooming by Bereuter et al. (2012). The alteration of the level of detail is more complex than map scale, and must be achieved through analytical procedures that work upon the map data, such as generalisation. Often the level of detail and map scale is positively correlated, and changes in one follow changes on the other, in order to keep the density of information equal between zoom levels. Temporal zooming has been implemented to navigate through a continuous interval of time, cyclic time or discrete events in time, a more thorough description of this process can be seen in (Hornsby 2001) or (Neumann 2005). However, what all these zooming processes have in common is the ability for a user to alter the part of the information space that is focused upon, and thereby support their perception of a phenomenon and the knowledge to which the perception leads. The definition for zooming in this section is therefore 'a mechanism to change the scale at which one perceives and conceptualizes' a visual representation, based partly on the definition given by Kuhn (1991). This definition makes it clear that it is the perception of the individual that is being supported by the zooming, and is general enough as it does not explicitly describe scale in terms of only map space.

The next question to be answered within the source domain is how individuals commonly alter the extent being focused upon. It is the familiarity with the interaction methods used to zoom a map that will enable an individual to recognise the interaction method required by them in order for the relevance zooming to take place. The tools used to zoom a map consist most commonly of a slider bar, with a **+** sign positioned at the top and a **–** sign at the bottom. This configuration assumes that users can intuitively link the up direction to a reduction in the map extent, and it has been suggested that this makes use of a common link that exists between the image schema up-down and the concept of more and less found in many other controls aside from maps, such as stereo volume (Battersby 2008). To look further into this question an analysis of twelve global web mapping services was undertaken, based around a Wikipedia page that lists global online web mapping services as shown below in Table 6.

Global Web Maps
OpenStreetMap
ArcGIS Online (Esri)
Google Maps
Map24
Bing Maps
ViaMichelin
MapQuest
WikiMapia
Nokia Maps
NearMap
Mappy
Yahoo! Maps

Table 6 – List of online web maps surveyed (taken from http://goo.gl/B2OnY)

This analysis clearly found that the up-down configuration is the most popular implementation for these web mapping interfaces. All web maps used this orientation except for Bing maps, which features the left-right configuration, even though the scale slider remains configured to the up-down metaphor. When developing a relevance zooming tool, this up-down mapping is therefore preserved, as it appears to offer both the most familiarity and also intuitiveness in the underlying mapping. Therefore to focus in more detail on relevance, an individual will zoom in and this will be carried out by interacting with the top section of a vertically oriented interface element.

6.5.2 A target domain of relevance zooming

As discussed in the previous section, it is not only the elements of space and time that are 'zoomable', but also theme and content, with often more than several of these elements zoomed simultaneously. For geographic relevance these different methods of zooming all have a role to play in the creation of a relevance zoom, and can influence how the state of the interface will be altered when a zoom operation is performed. The types of zoom that are possible to incorporate into a relevance zoom are described below, and allow the alteration of the extent of map space, the spatial representation and the map symbologies. Graphical examples of these zoom processes are shown in Figure 44.

Semantic Relevance Zoom – This zoom will operate in the attribute space of a relevance dataset, and bring about changes in the visual appearance of the map symbology which is commonly used to visually communicate the relevance scores held within the attribute data. When implementing a semantic zoom for relevance datasets, it is first necessary to define how the concept of *range* or *granularity* can be applied to a range of relevance values, since these concepts are tightly bound to the operation of zooming (Hornsby 2001). Figure 43 shows graphically how these two concepts can be related to relevance. Essentially the *granularity* of a relevance attribute space is a function of the number of categories used to divide this space. A greater number of categories result in more detail, a greater ability to differentiate between objects based on their relevance scores, and therefore a higher granularity. Therefore zooming results in the re-categorisation of the relevance values to incorporate more (zooming in) or fewer (zooming out) categories (Figure 12, left). The symbolisation can then be amended to communicate this re-categorisation process.

The definition of a *range* for the relevance attribute space is defined as the range of relevance values viewable. The range of relevance is calculated by subtracting the minimum value of relevance in the attribute space from the maximum value of relevance in the attribute space. This extent is therefore altered by filtering out objects from the relevance attribute space, with a zooming in interaction resulting in the removal of map objects, and zooming out resulting in objects being added. An example of this can be seen below in Figure 43 (right), with the filtering process removing the least relevant object (F) during the first zoom step, followed by the second step removing the two least relevant objects (E & F). Each step decreases the range of relevance between the most relevant object and the least relevant object. As objects are removed, the borders of the categories are amended to communicate the new range of relevance resulting from this filtering process.

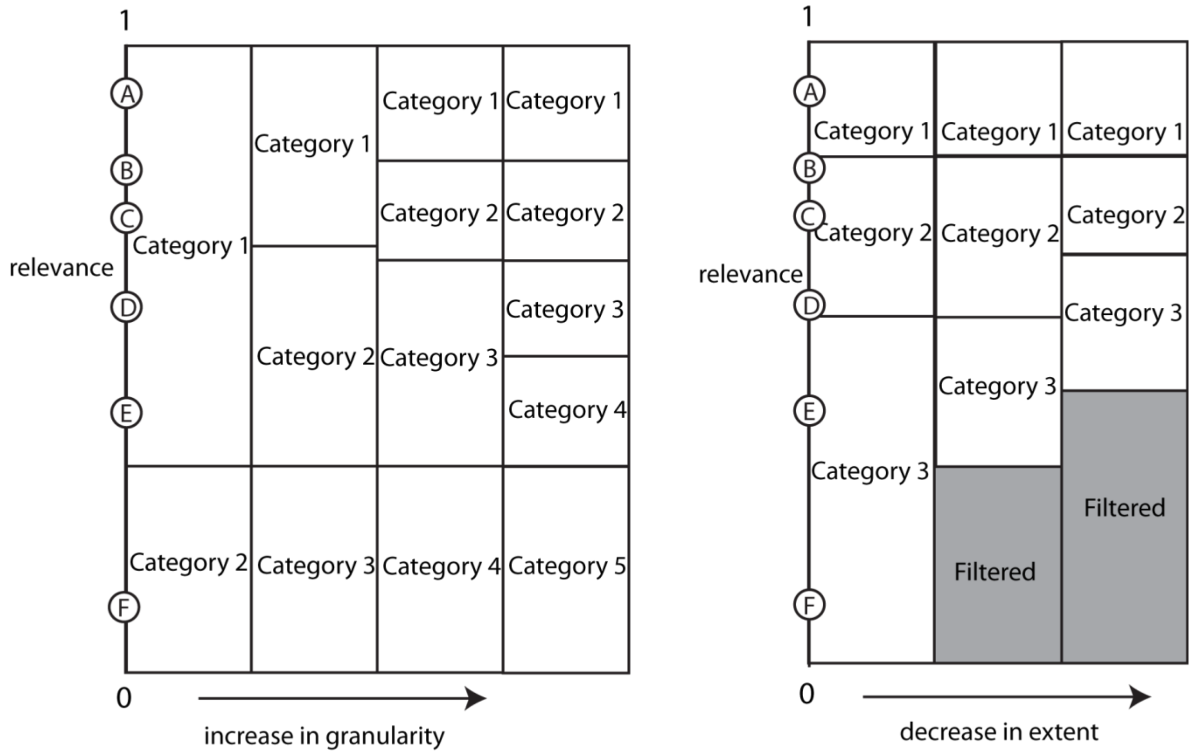


Figure 43 - Example of zooming in on the granularity and extent on a relevance attribute space for six relevance assessed objects (A-F).

Physical Relevance Zoom – The physical relevance zoom is interpreted as changing the extent of the map by linking it to the spatial extent of a number of relevance map objects. For example, a zoom operation can take place by finding the spatial extents of the top 100 objects and then fitting the map extent of these 100 map objects. The map extent could also be defined with a relevance threshold, e.g. the extent of all objects where relevance > 0.7, and then setting the extent of the map to the extent of these objects. This process can be done in gradual steps by removing one object at a time and re-computing the map extent, or in discrete jumps, e.g. remove 25% of the dataset and re-compute the new map extent. combination with this physical zoom process.

Content Relevance Zoom – Apart from the alteration of the map objects and the map extents, the spatial representation can also be amended, to give more or less detailed information as to the location of relevance. Many possibilities present themselves as a method to change this precision. One possibility is to employ map generalisation techniques such as aggregation of single point objects into single compound objects, an example of this can be found in Bereuter et al (2012). A second option is to represent the zoom as a gradual change from a density surface to point objects, as shown above in Figure 44. The strength of this approach would be in the

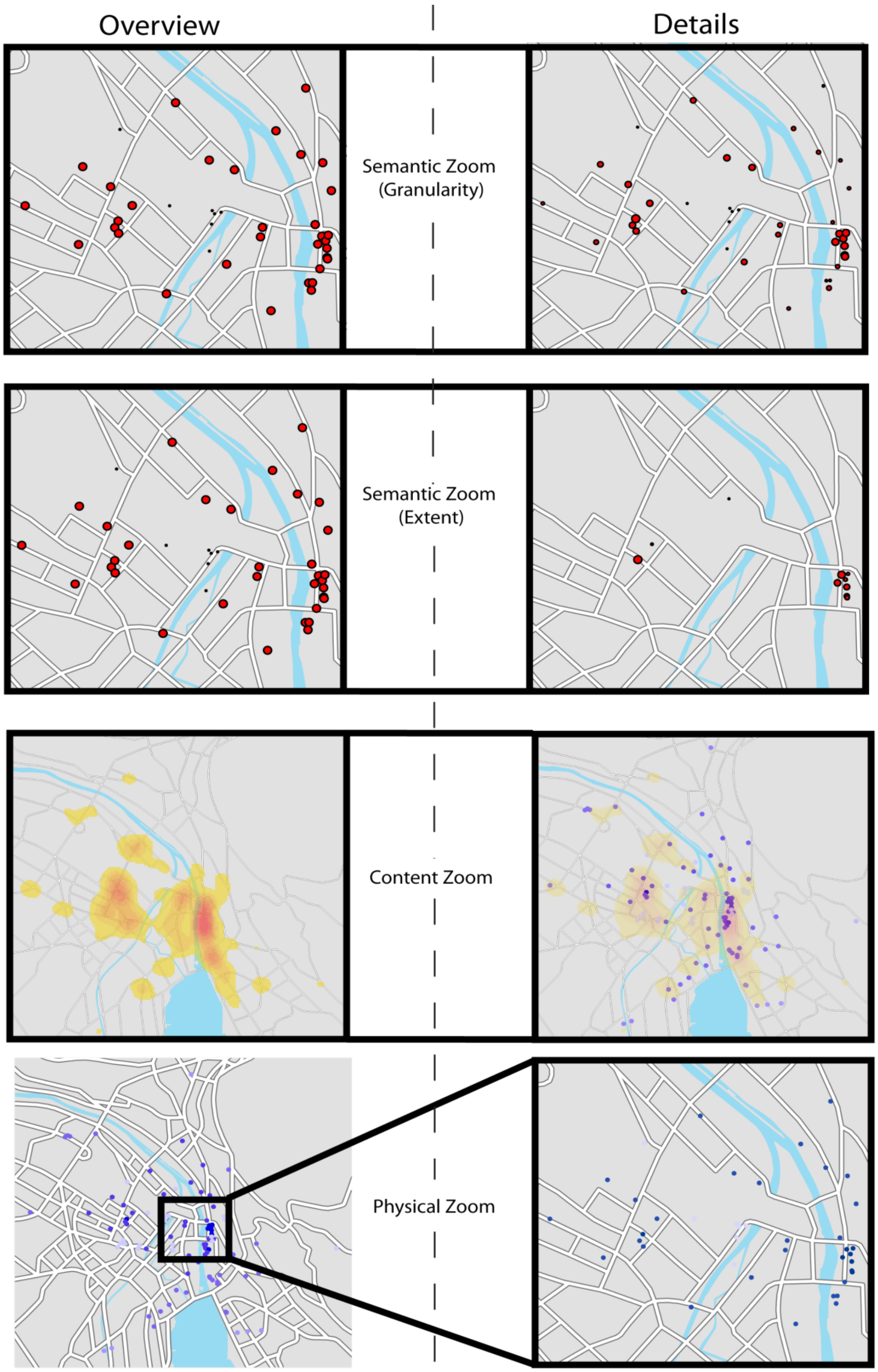


Figure 44 – Example visualisation of four relevance zoom processes for an overview and detailed view

preservation and communication of spatial relevance patterns, which conventional generalisation does not always uphold (Edwardes et al. 2005).

All the zooms processes described above can be implemented separately or be linked together. Linking them together would mean that interacting with a single zoom tool would result in two or more of these zoom processes taking place synchronously. Which zoom processes are applicable to any given implementation would require analysis for the user's goals or visual tasks. In general, the zoom processes can be split into two generic types, those that increase information density and those that lower it. For example, the semantic zoom of granularity results in a larger quantity of information being portrayed, as more categories are created and visualised. The same applies for the content zoom, as the detailed view removes the aggregation of the content, and instead portrays all the individual map objects. These zoom processes therefore are more applicable to exploratory visual tasks. Lowering information density is most effectively carried out by the physical zooming method and the semantic zoom for the relevance extents. These both result in the density of information being lowered as they both filter map objects from the map view.

For a mobile use case, it is perhaps a combination of the semantic zoom of the extent and the physical map zoom that results in the most sensible approach, as mobile displays with high information density result in poor usability. This combination then produces a powerful means to efficiently lower the density of information. In the next section an implementation of such a relevance zoom is therefore described in more detail.

6.6 An implementation of relevance zooming

The implementation described in this section is designed to allow the individual to be able to discover and focus on small sets of relevant objects within the map display in an efficient way. An example of the relevance zooming process is shown in Figure 45, describing the process of zooming in from 700 map objects to 300 map objects and how the categories and map extents are affected by this process. Two important points not considered by the above section, but necessary for an implementation, is the design of the relevance zoom interface tool and the visual alteration to the map display that occurs during the relevance zooming.

Although the actual interface element used for relevance zooming could be implemented in a number of ways, the design proposed here is based around a slider control and an up-down orientation, with the up mapping to zoom in and down mapping to zoom out. As it may not be obvious to the user what the affect of zooming in might be, information is displayed to allow the user to understand the affect of zooming upon the extent of the relevance dataset. This information relates to the number of relevant map objects that are visible and the total amount

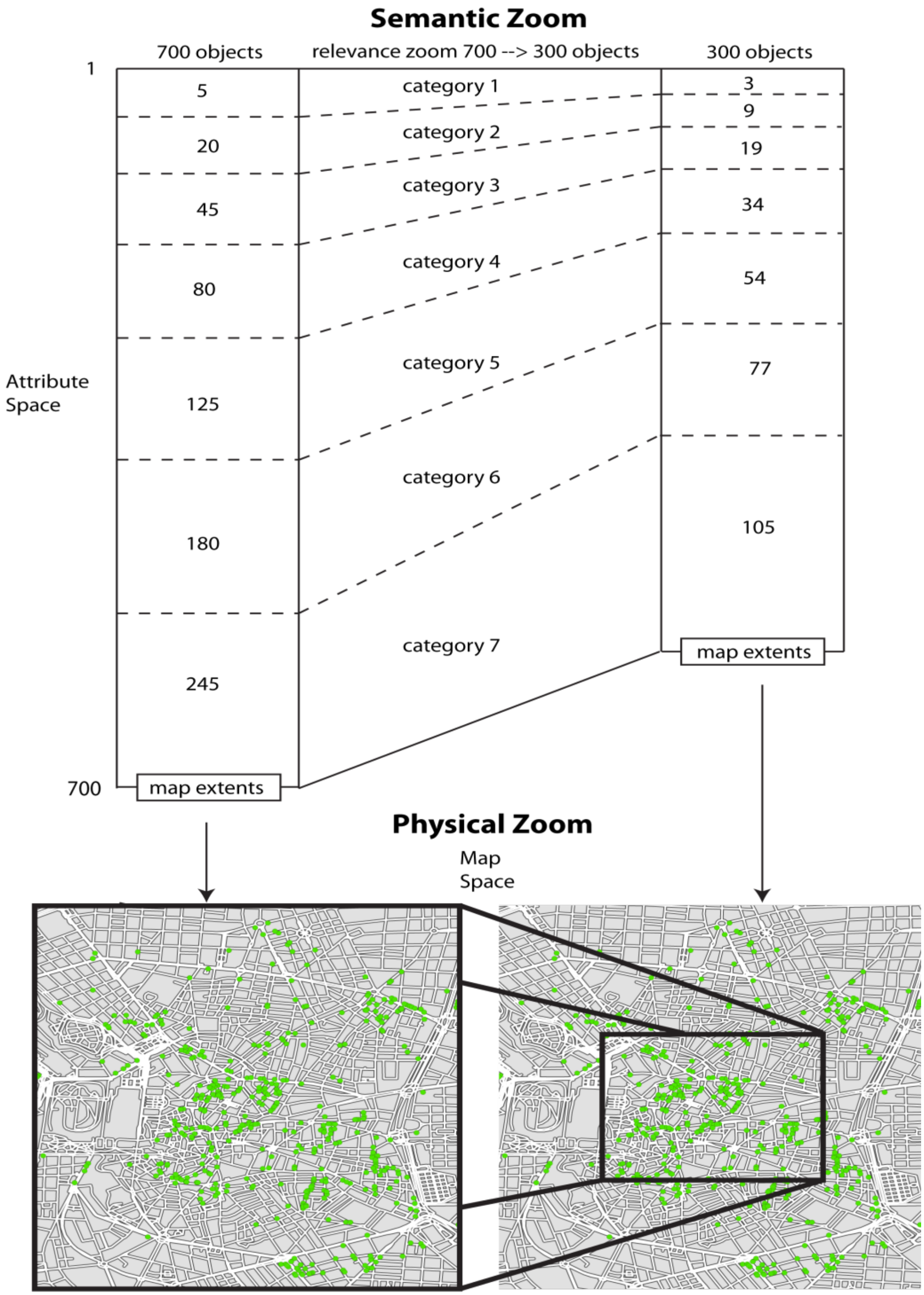


Figure 45 – Relevance Zooming from 700 to 300 objects

within the dataset being zoomed, e.g. 76 out of 438 places. An example of how this information is presented can be seen in Figure 46, which displays an information box explaining that 10 places from only 100 remain visible. An important behaviour of a slider is that it can support both a slow gradual zoom, and a zoom that iterates quickly through the zoom levels whilst also giving the user control over the exact behaviour desired (Harrower and Sheesley 2005). Therefore the slider in this implementation is designed to support both zoom behaviours, and is shown on the left hand side of Figure 46. Moving the slider upwards from the centre results in zooming in, moving it downwards results in a zooming out. The further the slider is moved from the centre, the faster the iterations are performed and thus the more relevance and map extent is altered, allowing the relevance zoom to progress more speedily. This allows the speed of the zoom movement to be controlled by the individual, and therefore results in more control over the size of the result set that an individual chooses to zoom into.

Figure 46 – Example of the relevance zooming interface with overview (left) zooming in (right)

The visual feedback that is produced by relevance zooming in this implementation is through alteration of the map extents and map symbols. For explanatory purposes, the visual variable of size is used to communicate the relevance category of each map object in the example screenshot in Figure 46, but any other visual variable could be applied.

As the zoom progresses, a re-categorisation process takes place, using the categorisation function described above in section 6.1.3. Each iteration of the zoom then remaps the new relevance categorisation to the visual variable of symbol size. The semantic zoom of extents included in this implementation keeps the number of categories constant whilst decreasing the number of map objects, which results in fewer objects per category and therefore a greater ability to differentiate between the relevance of the objects. This increased ability to differentiate between the objects should aid the visual comparison of the objects, and help the user discover the most relevant objects.

6.7 Summary

This chapter described the process of categorisation and metaphor development, so that the communication of geographic relevance and interaction with relevance datasets might be enriched. Categorisation of relevance scores could be carried out for both purposes, but this chapter utilised them as an enrichment of interaction. The aim of building categories was to offer a means to narrow down the result set, by applying a faceted search to the resulting categorisation. This enables an efficient means for the search to be narrowed down to only a small collection of objects through exploration of the relevance dimensions and the iterative specification of thresholds. The metaphors discussed here build on work by Reichenbacher (2005b), who discussed a graphical map design that incorporated metaphors of relevance. This work was furthered in two ways. Firstly, linguistic metaphors of relevance are explored through the analysis of web documents and crowd sourced information to refer to degrees of relevance using the underlying concept of the SCALE image schema. It became clear from these analyses that there is evidence to suggest that relevance is typically communicated with linguistic hedges. This agrees with the opinion of Johnson (1987), that "*this 'more' or 'less' aspect of human experience is the basis of the SCALE schema*". Secondly, the visual metaphors were given grounding in the application of linguistic theories in the form of basic domains and image schemas, in order to find concepts that can be symbolised on map displays. Chapter 7 will focus on empirically validating methods/concepts developed in this section, to discover if this approach does indeed enable the intuitive conveyance of geographic relevance. Basing metaphors around the bodily experience of individuals should give them the ability to be understood by a wide range of cultural and social groups, although further testing would be required to provide evidence of this assertion. Metaphors are also applied in the development of a map interaction design that allows relevance to become the subject of a zoom operation. An implementation of the relevance zoom concept suggested that a small, highly relevant subset of objects can be extracted efficiently by applying several existing zoom concepts to geographic relevance. Overall, this chapter suggests metaphors have an important role to play within the communication and interaction with geographic relevance, because they have the potential to enable the abstractedness of geographic relevance to be reduced.

Chapter 7 Empirical Evaluations

This chapter contains a description of three experiments that were carried out in order to explore how the design of visual representations of geographic relevance might affect the ability of individuals to intuitively understand the meaning of these visual displays. Previous work has looked into the ability of a visual representation of geographic relevance to draw the attention of the user to the most relevant objects through consideration of visual variables and saliency of map symbology (Swienty et al. 2008b). By approaching the same problem from another direction the design of the three experiments builds on this work. The experiments discussed below therefore do not focus on how well the map symbology attracts visual attention, but instead explore how intuitive these map representations are, and seek to explore whether an individual can easily relate the visual representation to the relevance of the map objects.

The experimental approach taken is a mixture between online studies and controlled experiments aiming at answering research questions 4, 5, and 6 defined in Chapter 1. These research questions are:

5. Which visual variables offer an intuitive representation of geographic relevance?
6. Do visual metaphors of relevance aid the communication geographic relevance?
7. Do explicit visual representations of spatial relationships improve the intuitiveness of geographic relevance?

The description of the three experiments follows the order of the questions listed above, with Experiment I attempting to answer research question four, Experiment II answering research question five, and Experiment III answering research question six. Experiments I and II are online studies and aim to gauge the ability of individuals to decode the meaning of relevance encoded using map symbols and visual metaphors. Experiment III is a controlled experiment that utilises not only performance measures as the dependent variable, but also eye tracking to determine the influence of the visual representation on the cognitive processes of each participant.

7.1 Experiment I – Map Semiotics

As the information seeking activities requires a user to understand which information is relevant and which information is not, this experiment focuses on analysing different symbolisations for the visual communication of geographic relevance, and whether these communications are understood intuitively or not. The main research questions that this experiment seeks to answer is the fifth research question defined in Chapter 1:

Which visual variables offer an intuitive representation of geographic relevance?

The study makes use of an online questionnaire to answer the above question. All subjects were asked to find relevant geographic information objects based on map displays that communicate the relevance rank of each object using visual variables. Three levels of the independent variable for the proposed experiment were utilised; the visual variables of colour hue, colour saturation and opacity. The task was to estimate the ordinal relevance of objects with the goal being to select a number of relevant objects and rank them according to their relevance. Exactly how relevance was visualised was not explained to the subjects. It was hypothesised that if the representations were intuitive then the subjects should be able to decipher the representation without this information being explicitly given to them. Intuitiveness is therefore defined as the ability of the participants to correctly rank the map objects based on their relevance, without the explicit explanation of the mapping between visual variable and relevance being given, such as a map legend.

7.1.1 Method

The visual variable was chosen as the independent variable, and response accuracy was the dependent variable. Three maps were generated for each experimental condition. The distribution of the geographic information objects was varied on each of these maps to prevent any potential bias being introduced. In addition, the order that each condition is presented to the subjects was varied to also lessen any possible order bias (S1-S9 in Table 1 - Appendix 2). This would result in 18 separate display sequences. However, to minimise setup times of the experiment, this was condensed to 6. This simplified version results in the Latin Square shown in Appendix I.

All subjects were divided into equal numbers between the six sequences. Three example questionnaires for each condition are shown in the materials section. The experiment followed a within-subject design, with all participants viewing all three conditions of the independent variable, defined in the section below.

Independent Variable: The independent variable was the visual variable employed to map the geographic relevance values to map symbols. The three levels of the independent variable *visual variable* were colour saturation, colour value, and opacity. Although symbol size has often been found to provide a good encoding for ratio and ordinal values in other empirical mapping studies (Garlandini and Fabrikant 2009), this variable was not considered due to its unsuitability for small screens, which in the context of this research is an important factor. The visual variable was different for each condition. This allowed to test if the type of visual variable has any impact on a subject's understanding of the mapping. Additionally, the subjects were asked to communicate on what they based their judgements, so that any judgements based on something other than the visual variables could be excluded.

Dependent Variables: Relevance was treated on an ordinal level of measurement, as the task required the subjects to rank the map objects by relevance. Accuracy was calculated as the deviation between the pre-defined relevance rank of each map object, and the rank allocated to it by the participant. Furthermore, the number and size of deviations between the perceived and pre-defined relevance rankings was also investigated, in order to measure the degree and frequency of ranking errors for each visual variable. This was calculated by comparing all perceived rankings for all objects with all the pre-defined rankings. Thresholds were then set to count the number of deviations that were greater than 2, 3, 4 and 5.

Controlling Confounding Variables: Decision complexity is defined by Payne (1976) as – "*number of alternatives available and number of dimensions of information available per alternative.*" This means that complexity could potentially be increased by keeping the number of alternatives equal but increasing the number of dimensions of information available or vice versa (increase in dimensions of information) or by increasing both. For maps the alternatives can be thought of as number of map objects and the dimensions as the number of attributes for each object that participants had to incorporate into the decision making process. Therefore, the decision complexity was controlled by keeping the number of map objects constant between tasks and to vary only one visual variable on each map. Visual complexity was kept constant by introducing the same number of objects across all stimuli. The basemaps were designed as simply as possible so that the map display remains uncluttered and the map scale was kept constant. The maps were static images and therefore the variance across participants regarding the ability to interact with digital maps, e.g. zooming, panning, was removed. Furthermore, the area used in the study (Baghdad) was very likely unfamiliar to any of the participants and map scale is kept constant across all tasks.

Participants: In total 33 respondents took part in the experiment. These participants were recruited through an internet mailing list moderated by the Commission for GeoVisualization of the International Cartographic Association, established in 1995. The followers of the list are therefore academics and professional interested in research oriented towards the development of geo-visualisations. It is acknowledged that this has perhaps two disadvantages. Firstly, the experiment becomes less controlled and secondly, the respondent group is rather homogeneous in terms of their professional/educational background. However, the advantage of a homogenous group of participants is that variance between individuals is lessened and therefore lower levels of bias result.

Materials: The Onlineumfragen.com software was used to prepare and distribute the questionnaire. The maps used as stimuli and presented in the questionnaire were created using OpenStreetMap (OSM) datasets and ArcMap. The geographic information objects are all fabricated. Examples of these map displays are shown below in Figure 47. Each of these map displays was accompanied by the same scenario, which described a tourist seeking a hotel in an unknown city. The same scenario was used for all stimuli presented to the participants. The scenario is shown below:

Figure 47 - Example stimuli for Experiment I

You are visiting an unknown city as a tourist. Your first task is to find a hotel. You use a map application on your mobile device to search for the hotels nearby. To further aid your decision the application has state-of-the-art functionality which offers you a visual guide to help you easily find the more relevant hotels. After submitting a query the application brings up the following map screen displaying the location of hotels.

Procedure: The experiment took the form of an online questionnaire. A link to the introduction page of the questionnaire was emailed to the mailing list with information about the background of the experiment. After the introduction the participants could proceed to the next step of the experiment by clicking on a button located beneath the text. This directed participants to the onlineumfragen.com website and the questionnaire (an example of this interface can be seen in Appendix III). As the onlinumfragen.com website did not allow randomisation of questions, it was necessary to prepare six separate questionnaires, with a small script dividing the subjects into equal numbers between the six questionnaires.

The first question allowed the subjects to test out the rating scale that would be used within the main questions so that they could become familiar with the rating method. This required the users to drag and drop boxes labelled analogue to the map objects into an ascending order. Once this test question was completed, the subject could proceed to the three main questions. A final question allowed the participants to explain on what they had based their ratings, to confirm that the visual variables had been used and no other information on the map display. Finally, a screen was presented to the participant to thank them for their involvement.

7.1.2 Results

The analysis first looked into the number of participants that managed to understand that visual variables were being used to represent the geographic relevance. In total 63% (N=21) participants were able to base their judgements on only the visual variables, 27% (N=9) participants used other information within the map display whilst 10% (N=3) used a mixture of visual variable and other information. An example response from a subject who based their judgements on other information explained that they used the '*proximity to parks, arrangement of streets*' to judge the relevance of objects. An example of the mixture group responded either by using only visual variables on some conditions and other information on others or mixed it together for all the conditions.

The remainder of the analysis therefore focused on the 21 respondents that did use the visual variables to judge the geographic relevance of the map objects. This analysis looked in more detail at the ability of the respondents to understand the correct rankings from the visual variables. A spearman's rank correlation was run on the responses to measure the level of agreement between the perceived rankings with the pre-defined rankings of the map objects (Figure 48).

The average Spearman's rank correlation (rho) shows that in general the participants were able to correctly rank the map objects for all conditions. All correlations are statistically significant. However, opacity has a slightly higher rho value (rho=0.95) than the other two variables, value (rho=0.72) and saturation (rho=0.76). To measure the degree of variance in interpretation, the standard deviation of the rho values was calculated, and shown as bars in Figure 48. This shows a greater variance of rankings for the visual variable value and saturation, which means participants' interpretations were less often in agreement than for opacity. A further descriptive measure computed was the minimum, as a low minus value would indicate that some participants were reversing the mapping of geographic relevance values to the visual variables. It was found that this was the case for saturation and to some degree colour value, both of which recorded negative rho values.

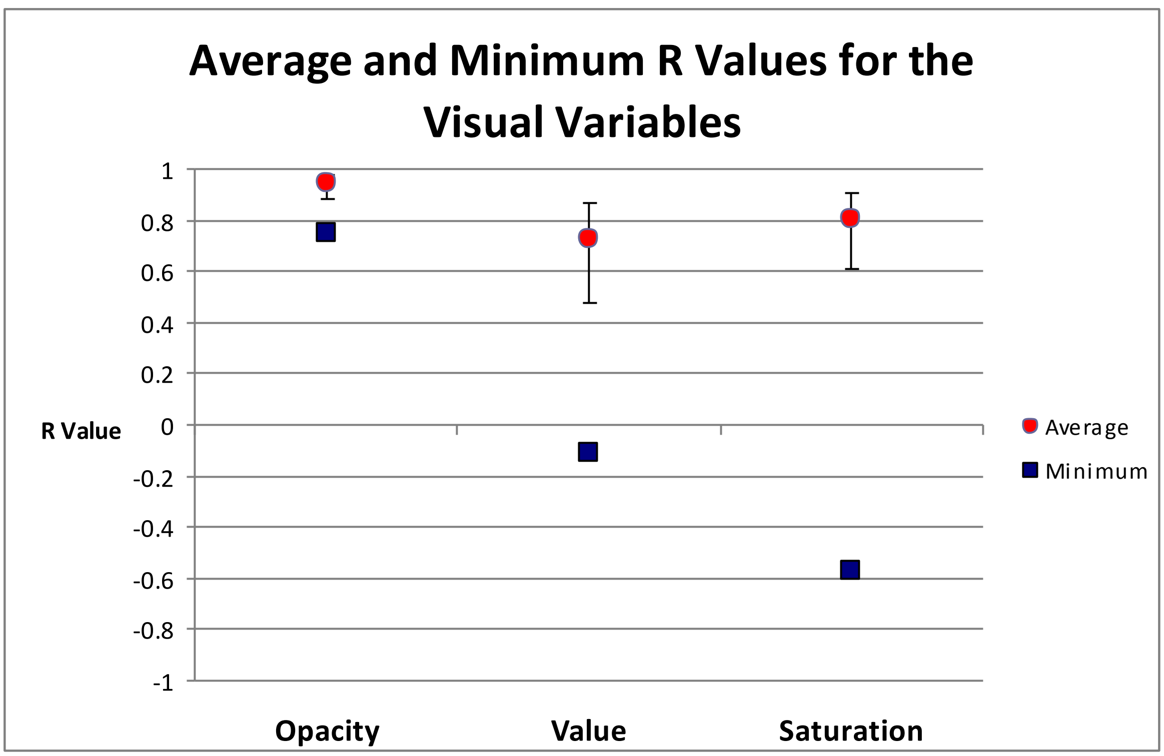


Figure 48 – Spearman's Rank Correlation for the responses of each visual variable condition

To explore this observation further, the data was analysed to discover how the ranking of the subjects differed from the actual rankings of the map objects. This was carried out by looking at the difference between the pre-defined ranking of the map object and the ranking given to that map object by each participant to yield a distribution of errors in the ranking. For example, if the actual ranking of a map object was 4 (4th most relevant object) but the participants provided a ranking of 7 then the error would be the absolute difference between the two, which in this case would be 3. The errors were explored where ranking error=2 up to ranking errors=5. The count of errors where the deviation was equal to 1 and to 6 were both ignored, since there were numerous deviations equal to 1, and these were equal across all independent variables whilst no deviations of 6 were recorded for any participant. This was therefore most likely a result of the participants not being able to differentiate between slight changes in opacity, value or saturation rather than a misunderstanding of how relevance as represented, which was the goal of this analysis.

The resulting graph is shown in Figure 49. This analysis suggested that two of the visual variables produce rankings that contained large errors. Colour value has 2 rankings with an error of greater than or equal to five, and opacity produced three of these errors. Opacity was ranked with the least errors overall, containing only one error at the >2 error level. Colour value contained the greatest number (16) of ranking errors at the >2 error level followed by saturation (10). Looking into more detail at an individual level, it was found that two individuals had ranked the objects in reverse order.

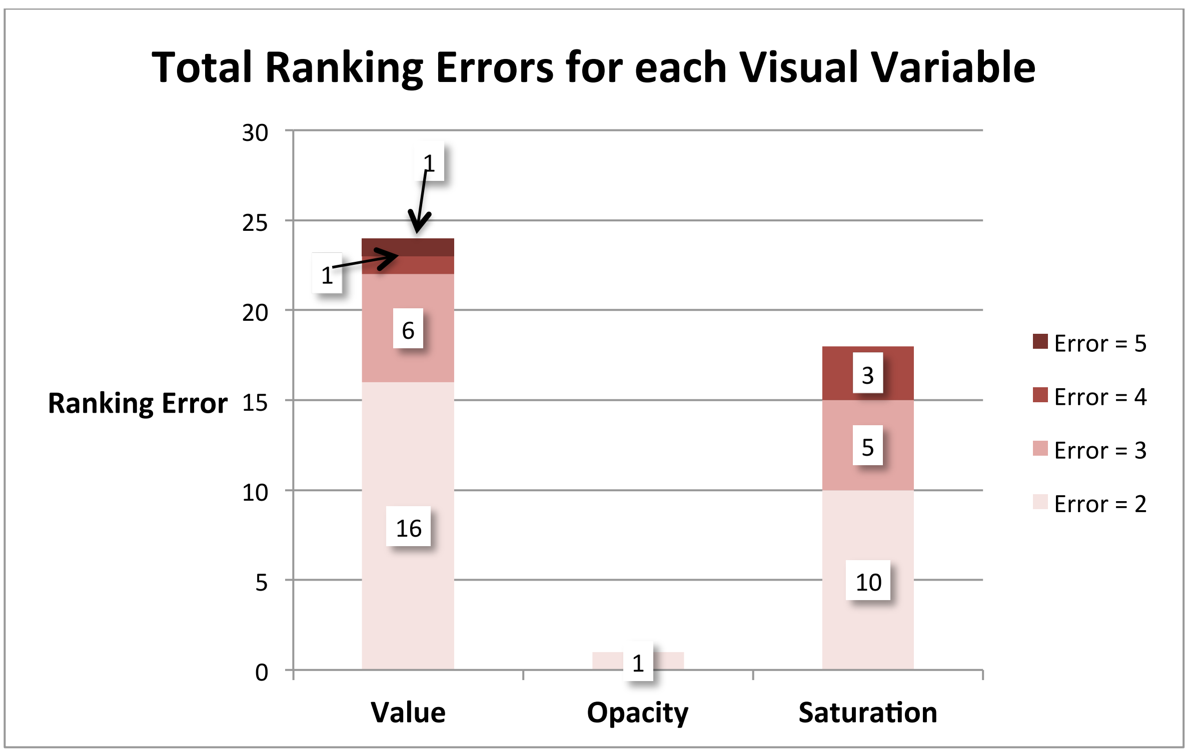


Figure 49 – Frequency and magnitude of errors in rankings

7.1.3 Summary of Results for Experiment I

The main findings of Experiment I are that visual variables are able to intuitively represent geographic relevance, but only when they are properly recognised and understood. Even though participants can be assumed to be experienced in geovisualisation, only 63% were able to recognise that visual variables were being used to communicate the relevance of map objects. However, when looking at the results for those who recognised the geographic relevance encoded as visual variable, there is clear evidence that opacity offers an intuitive encoding of relevance. This evidence is also shown in the analysis of errors in rankings for the visual variables, which also favoured opacity. These results also suggest that users can better differentiate between the opacity of map objects, as shown by the low number of errors in all levels of ranking. Agreement for the success of opacity to encode the relevance of map objects results can be found in other empirical studies, which strongly suggests that opacity map most closely to the concept of geographic relevance (Olivieri 2012). However, as explained in Chapter 6, aside from visual variables, metaphors can also be used to visually communicate relevance. This finding therefore leads to the next experiment which seeks to discover if metaphors exist that offer the same or better mappings to relevance than opacity.

7.2 Experiment II – Metaphor

Experiment II builds on Experiment I and uses a similar experimental design. However, it takes a different approach to test the intuitiveness of GR representations for information seeking activities of mobile users through visual metaphor use. Specifically, this experiment seeks to discover evidence that information seeking from cartographic representations will benefit from the application of visual metaphors. The research question that this experiment sets out to answer is the sixth research question:

Can visual metaphors of relevance provide intuitive mappings to geographic relevance?

Aside from the results of Experiment I offering the opportunity to compare metaphors with visual variables, this experiment was also motivated by the work carried out in Chapter 6 that explored the development of visual metaphors for communicating geographic relevance. Although in Chapter 6 ten possible metaphors were proposed, a subset of four was chosen to allow the experiment to be completed rapidly and encourage participation. These four were selected as they had also been previously discussed in other work (for example (Reichenbacher 2005b)), which therefore provides evidence that they may provide the better mappings to geographic relevance. This subset consisted of two metaphors from the image schema FULL(relevant)-EMPTY(not relevant) and HIGH(relevant)-LOW(not relevant) and two from the basic domain group LIGHT(relevant)-DARK(not relevant) and HOT(relevant)-COLD(not relevant). Additionally the visual variable opacity was included to measure how the metaphors compared with the most successful visual variable discovered in Experiment I. How relevance is visualised was not described to the subjects. As with Experiment I, the metaphors are intuitive if the participants can rank the map objects accurately based on their relevance, without any explicit information being provided that describes the mapping of the metaphor to relevance rank. The hypothesis is that metaphors offer intuitive mappings to geographic relevance. The hypothesis will be falsified if the subjects are unable to rank map objects accurately based on their understanding of a specific metaphor.

7.2.1 Method

Experimental Design: The experiment used a within-subject design to answer the above question. All subjects were asked to find relevant geographic information objects using all five conditions of the independent variable, as defined below. These conditions were shown in a randomised order to prevent a possible learning effect, with a script assigning subjects in equal numbers to each randomised order. The Latin square for this randomisation is shown in Table 2 - Appendix II. The tasks of the participants were to rank these objects based on their perception of the relevance value of each map object. A textual description of this task, and a scenario was provided along with a static map to the participants. Additionally, the subjects were asked to communicate on what they based their judgements, so that any judgements based on something other than the metaphor could be excluded.

Independent Variable: Each condition includes a different type of metaphor. This will allow the experiment to test if the type of metaphor has any impact on a subject's understanding of the geographic relevance representation.

Dependent Variable: Relevance is treated on an ordinal level of measurement. Accuracy is measured as the ability to correctly rank the relevance of represented map objects based on metaphor recognition and understanding. This relevance rating accuracy was measured as the difference between the pre-defined relevance rank of the map objects, and the rank assigned to each object by the participants. The recognition and understanding of the metaphors tested was gauged through an analysis of the comments by the participants that described how they made their decisions. For each metaphor type the number of participants that mentioned the metaphor explicitly in their comments was counted.

Controlling Confounding Variables: The same controls were placed on this experiment as with Experiment I. The number of map objects, the map design, and level of interactivity was kept constant for all stimuli. However, a different geographic region, Pyongyang, North Korea, was used as the geographical footprint displayed on the maps. It was assumed that most of the participants were unlikely to have travelled to this place or studied a map of this area, and therefore unfamiliar with it.

Participants: In total 56 respondents took part in the experiment. These participants were recruited through the siguse-L and studentuse-L mailing list. These lists, used by professional and academic people interested in the field of information seeking and user studies were chosen for two reasons. Firstly, this removed a bias of the first experiment as, unlike the GeoViz mailing list, the majority of subscribers to these lists are not familiar with geovisualisation or cartographic theory. Secondly, the broader topic of this experiment would hold some relevance for the subscribers to these mailing lists, and therefore they are likely to be interested and motivated to take part.

Materials: Stimuli were prepared as part of the online questionnaire using the onlineumfragen.com website. Each survey question took the form of a scenario and a map display. Again, the maps presented in the questionnaire were all created using OpenStreetMap (OSM) datasets and ArcMap. Examples of these maps are shown in Figure 50 as LIGHT-DARK (image A), OPACITY (image B) HIGH-LOW (image C) FULL-EMPTY (image D) and HOT-COLD (image E). Above each of these static maps the same scenario, which described a tourist seeking a hotel in an unknown city was displayed:

You are visiting an unknown city as a tourist. You feel tired during your tour of the city and want to find a suitable Cafe. A map application on your smartphone allows you to search the city for Cafes. After submitting the query, this application returns the 5 Cafes that fit best to the needs expressed within the query you have submitted and displays them on a map. Furthermore, this map application has state-of-the-art functionality which offers visual cues to help you easily find the more relevant Cafes. These visual cues are represented within the map symbol used for each Cafe. Therefore you should base your decision solely on the map symbols.

After submitting a query, the application brings up the following map screen showing the locations of the 5 Cafes"

A rating tool was also displayed, with which the participants could drag and drop boxes which related to each of the map objects into an order based on the perceived relevance. An example of the interface used can be seen in Appendix III.

Procedure: The subjects were presented with an introductory text that explained to them that they will be shown maps that are displaying the relevance of objects and that they must rank the relevance of objects using these maps. A practice question allowed the participants to become familiar with the interface tool used to rank the map objects. Each subject then responded to the five questions, one for each metaphor type, and finally a question that allowed them to describe what the rankings were based on.

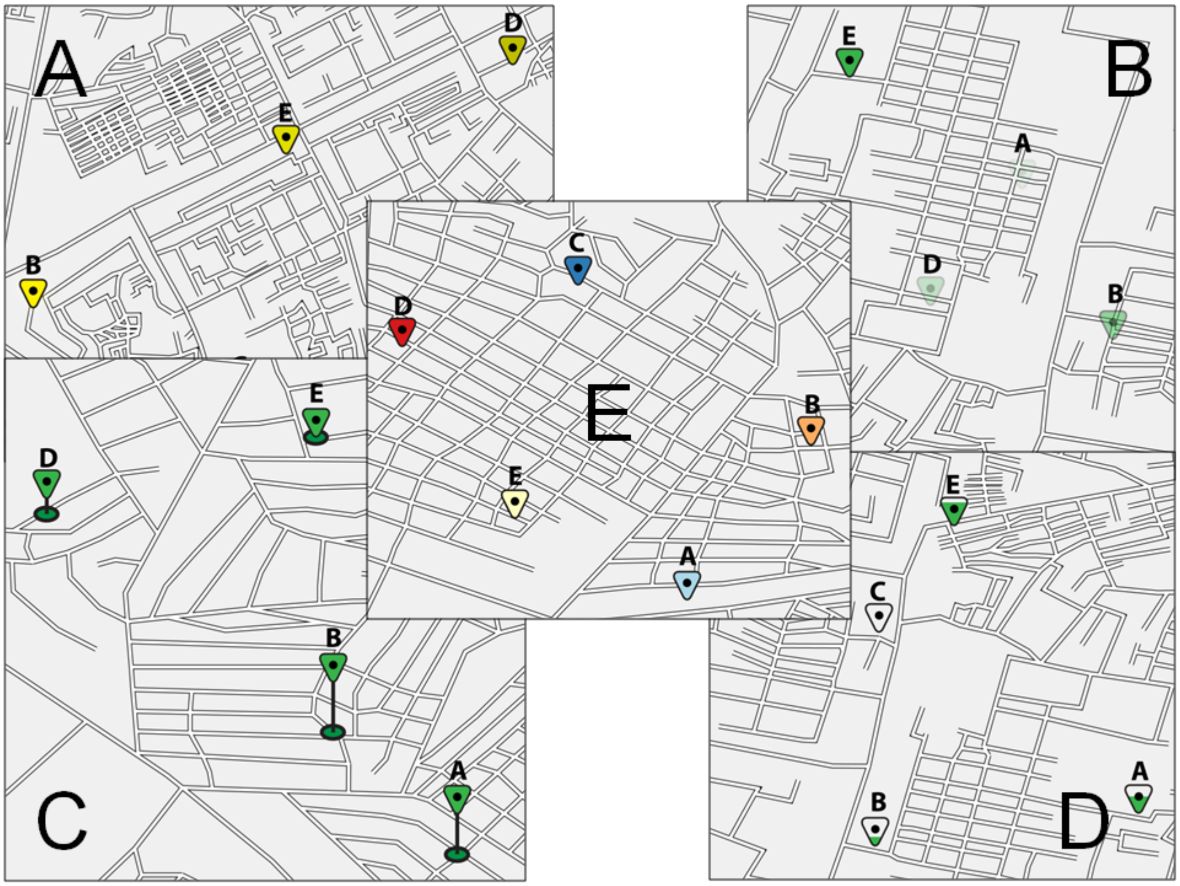


Figure 50 - Example stimuli for Experiment I

7.2.2 Results

The first step in the analysis was to remove any participants that did not finish the survey, or whose responses were not based on the use of the metaphors. There were 8 incomplete surveys, and 4 participants utilised other features of the map rather than the map symbology e.g. proximity of a map symbol to the centre of the map. Thus, the responses of 44 participants were used for the analysis.

First the descriptions given at the end of the survey were analysed to reveal the ability of the participants to correctly recognise the metaphor. If the metaphor used for a condition was explicitly mentioned then this was considered recognition. 39 participants from 44 gave a clear description for each question. 5 participants only gave a general description that simply stated that the design of the map symbols was used. The visual variable OPACITY and the metaphor

FULL-EMPTY were recognised by 39 respondents, and HIGH-LOW was also recognised by a significant majority of 29 participants. Both the LIGHT-DARK and HOT-COLD metaphors were more difficult to recognise with HOT-COLD being recognised 6 times and LIGHT-DARK only twice by the participants. The remaining participants simply recognised these metaphors as changes in colour values but with no reference to temperature or light. Qualitative analysis of the textual descriptions suggested that when the participants did not recognise these metaphors, they instead based their rankings according to cartographic theory. As lighter map symbols represent the most relevant map objects for a LIGHT-DARK metaphor, the mapping between relevance rank and the visual variable are reversed because for cartographic theory darker colours map to higher magnitudes. This should result in large deviations between pre-defined relevance ranks and perceived relevance ranks. For HOT-COLD, this results in a less severe effect on the comparison of the perceived and pre-defined rankings, as whilst the least relevant map object (dark blue) will be ranked highly, so will the most relevant (dark red). Furthermore, the HIGH-LOW metaphor shows similar effects, with some participants recognising the height of the map symbol to be related to relevance but describing the more relevant objects as being those closer to the ground. However, this effect is not related to the inability to recognise the metaphor, but in the mappings of height to relevance rank being reversed.

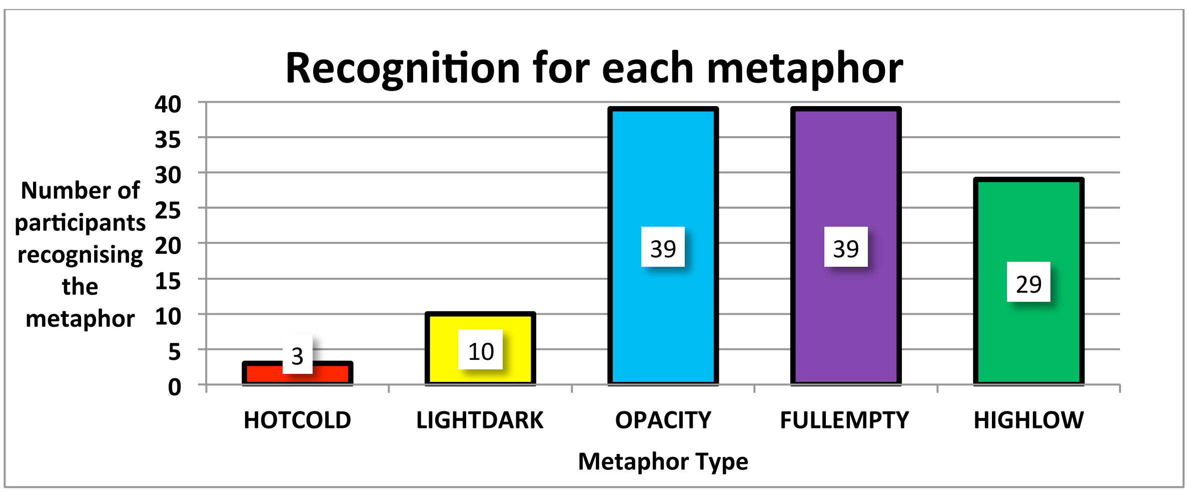


Figure 51 – Recognition for each metaphor

The next step analysed the actual and perceived rankings using the Spearman's rank correlation to discover which metaphors allowed the participants to perceive the correct relevance ranks of the map symbols. The ability of the metaphors to communicate relevance followed a similar trend shown above for recognition. FULL-EMPTY provided the closest match between actual and perceived rankings (*rho* =.97), with OPACITY producing a comparable level of agreement (*rho* =.91). HIGH-LOW gave the third highest correlation (*rho* =.66), LIGHT-DARK was fourth (*rho* =.39) and HOT-COLD was last with a very slight positive correlation (*rho* =.12). OPACITY, FULL-EMPTY and HIGH-LOW were found to be significantly correlated to $p<.01$ level of significance, and LIGHT-DARK at $p<.05$ with the actual relevance rank of the objects.

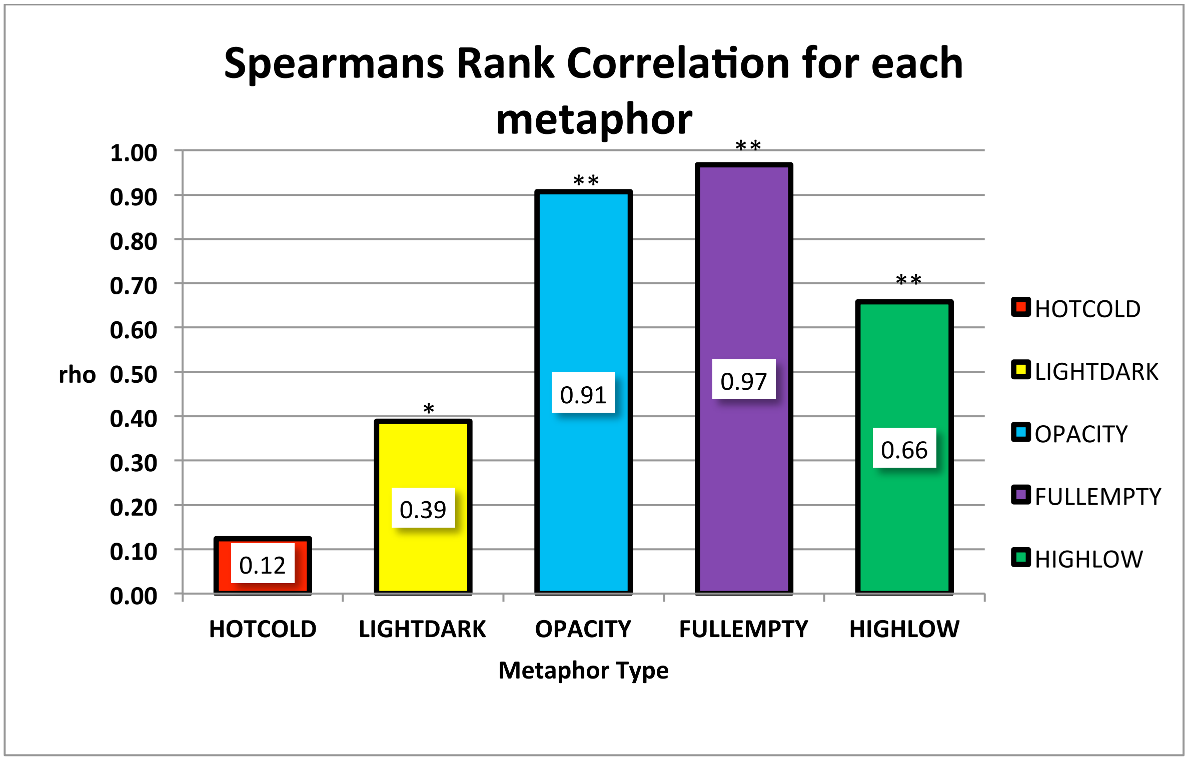


Figure 52 – Spearman's correlation *rho* values for each metaphor type (= $p<.01$, *=$p<.05$)**

Further analysis of the accuracy of the answers was carried out by looking into the distributions of the size and frequency of the ranking errors for each metaphor type. The ranking errors were calculated by taking each ranking given by each participant and comparing it to the actual rank, e.g. if the participant ranked an object as 4th most relevant, and it was actually 2nd most relevant, the calculated ranking error was 2. Each metaphor type therefore contained a total of 220 rankings (5 objects to rank per metaphor multiplied by 44 participants) Only 12 (5%) of the rankings for the FULL-EMPTY metaphor type contained an error for the 220 responses. For OPACITY this value was only slightly higher with 23 errors (10%). Interestingly, the HIGH-LOW metaphor produced a higher number of errors (111, 50%) compared to LIGHT-DARK (91, 41%), but the majority of these errors represented only ranking errors of 1 or 2. HOT-COLD produced the greatest amount of error with 152 of the rankings being incorrect. It also shows the greatest amount of ranking errors with differences between 3 and 4. It was the presence of these larger errors that resulted in low *rho* scores for both the LIGHT-DARK and HOT-COLD metaphors.

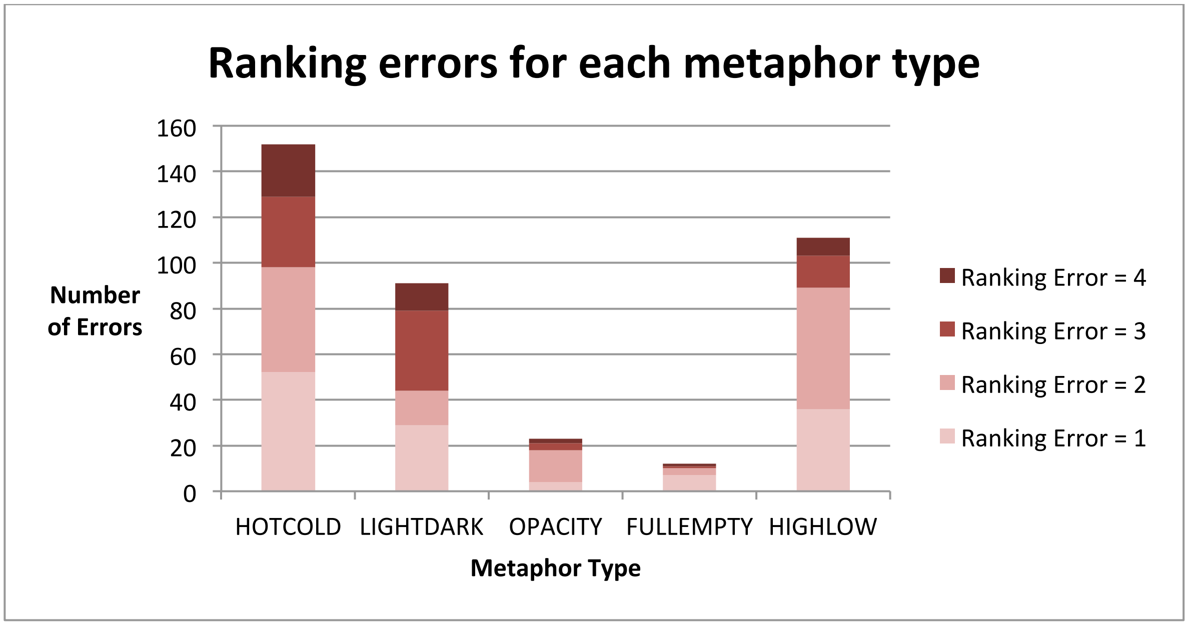


Figure 53 - Number and size of ranking errors for each metaphor type

7.2.3 Summary of Experiment II

Perhaps the most positive contribution from this experiment is that indeed there are metaphors available that can rival the more commonly applied map semiotic approach described in Experiment I. This can be seen with the excellent performance of the FULL-EMPTY metaphor. However, the experiment described above also clearly demonstrated that the metaphor type had a significant effect upon the perception of relevance by each participant. Therefore, in reference to the original research question of whether metaphors can provide intuitive mappings to geographic relevance, the answer is that they can. It would seem that the image schema metaphor (HIGH-LOW, FULL-EMPTY) allowed the participants to accurately recognise the metaphor being applied. However, after recognising the metaphor, the mapping to the relevance values has to be understood. The easier this process is, the more intuitive the metaphor will be. In this mapping process, the HIGH-LOW metaphor did not perform as well as expected. The recognition of the metaphor was relatively high but the correlation between the perceived and actual rankings was lower, due to errors that stemmed from some participants believing a symbol closer to the ground was more relevant than one higher up. The FULL-EMPTY metaphor did not have this problem, with high level of recognition being matched with a high correlation of rankings. The reason for this success can perhaps be explained by the strong visual indicator communicated by a full object. This strength is that FULL-EMPTY can clearly communicate ‘more’ of something, which in the context of this experiment means more relevance. This point could also be used to explain the success of opacity also as a more opaque object is more visible to a user and it is clear that this state of opaqueness is therefore indicating a state of relevance. The basic domain metaphors (HOT-COLD, LIGHT-DARK) resulted in much less recognition and more inaccurate rankings than for the image schema derived metaphors. Especially poor was the HOT-COLD metaphor, which received the lowest numbers for recognition, correlation values and the highest number of large ranking errors. As the map symbols used to communicate these concepts were abstract (only colour), this made the ranking task more difficult for the participants. The reason for this difficulty is perhaps that the meaning of colour can be perceived differently between individuals, whilst one individual might see red = hot = more relevant, another may see simply darker colours = more relevant. For image schemas, this problem of recognition is less prevalent and therefore the mapping task is the only problem that is faced. This is one possible explanation for the better performance of image schemas over basic domains. Aside from the design of map symbols discussed so far in this chapter, a method to design meaningful visual representations of geographic relevance was discussed in Chapter 5 of this thesis. The ideas for Chapter 5 are therefore tested in the final experiment described below in section 7.3.

7.3 Experiment III – Relationship Explicitness

Experiment I and II focused on assessing the intuitiveness of encoding relevance with map symbols. However, Chapter 5 suggests that perhaps just presenting map symbols to a user will not be sufficient for them to understand the specific relevance criteria that contribute to the relevance of the map objects, and that explicit representations of the relationships between map objects, such as route or cluster overlays, can provide support in this understanding process. Experiment III attempts to develop the findings in Chapter 5 further by focusing on discovering if *relationship explicitness* and *spatial frame of reference* improve the effectiveness and efficiency of the information seeking activities of mobile users.

The guiding hypothesis of this experiment is that visually explicit representations of spatial relationships that contribute to the GR of an object will help users to comprehend which objects are geographically relevant. This attempt also extends research that has focused mainly on the encoding of GR with visual variables of map objects and seeking to discover which visual variables are capable of guiding attention (Reichenbacher 2005b, Swienty et al. 2008b). A second line of research motivating several detailed research questions for this experiment stem from user studies that have looked at map orientation and recommended that an egocentric orientation enables users to more easily perceive the direction of objects in relation to themselves (Winter and Tomko 2004). These studies draw upon previous studies by psychologists and cognitive scientists into the use of external representations and diagrams and how they can enhance cognition and thus our understanding of abstract concepts, such as space (Hegarty 2004, Chandrasekaran 2006).

The research mentioned above is used as a theoretical basis for the experiment undertaken as they attempt to explain how an external representation can aid cognition, and therefore allows the formulation of hypotheses and research questions about how an external representation of GR should be formed in order for it to be usable and useful. The overall research question addressed by this experiment is the seventh research question listed in Chapter 1:

Do explicit visual representations of spatial relationships improve the intuitiveness of geographic relevance?

This guiding research question that the experiment will set out to answer is broken down into the following separate sub-questions:

Q1: Does encoding geographic relevance with opacity improve the ability of a user to discover the most relevant geographic information objects efficiently and effectively?

Q2: Does an egocentric map orientation improve the ability of a user to discover the most relevant geographic information objects efficiently and effectively?

Q3a: Do explicit visual representations of spatial relationships improve the ability of a user to discover the most relevant geographic information objects efficiently and effectively?

Q3b: Do route and arrow features improve the ability of a user to judge the spatio-temporal proximity of map objects?

Although geographic relevance can be composed of many different criteria (De Sabbata 2010), spatio-temporal proximity and directionality are in the focus of this experiment. These criteria were chosen as they were also the focus of a conceptual study (Crease and Reichenbacher 2011) regarding the incorporation of cognitive principles into a design process, and therefore this experiment offers the chance to empirically validate the concepts developed.

7.3.1 Method

The study followed a within-subject design to answer the above question. All subjects were asked to identify the most relevant geographic information object from mobile map displays, based on a given scenario and a given task description. The task involved the comparison of map objects from a map display based on the relevance criteria referred to as spatio-temporal proximity, and to some degree directionality. However, before this comparison can be carried out participants must first comprehend the relevance criteria of the map objects. It is the ability of the participants to intuitively comprehend these map depictions that is tested within this experiment. Exactly how relevance is represented was not described to the subjects to allow a thorough test of the intuitiveness of the visual representations. If the representations are understood, then subjects will be able to identify the relevant objects more efficiently and more accurately with an explicit visual representation of the encoded spatial relationships. If certain characteristics of the representation draw attention to relevant objects then we will also be able to sense this through the eye movement behaviours. As with Experiment I and II, the assumption is that if the representations are intuitive, subjects will be able to decipher the representation without this information being explicitly given to them. The assumption will be falsified if the subjects are unable to locate relevant map objects accurately based on the task description given to them.

Independent Variable: To successfully answer the research question the independent variable *visual explicitness* of the encoded spatial relationships was controlled in order to study if it has any impact on a participant's understanding of the displays. This *visual explicitness* is defined as the ratio between the total number of visual elements that could be used to communicate a relationship and the total number of these elements that are visualised, i.e. explicitly used in the map representation. Figure 54 displays the five visual elements for the criteria spatio-temporal proximity and directionality: origin, destination, route, arrows, and opacity. From this definition, we can then say that displaying the relevance with the opacity of map symbols only will result in a visual explicitness of 1/5. Including additional information, such as the start and end destination will lead to a visual explicitness of 3/5. The dependent variables can then be compared against these values to discover the effects of varying these levels of visual explicitness. Additionally, the orientation of the map was also varied between being oriented towards the direction of travel (egocentric) or oriented towards North (allocentric), in order to explore how this affected the performance of the participants. However, as no extra information was added by this adaptation it was not considered as adding to the visual explicitness.

Although it would be possible to use every combination of visual elements and map orientation, it is obvious that some combinations do not communicate the spatio-temporal proximity of objects to a subject, e.g. when only visualising the origin. Therefore only combinations were included which hold enough information for a subject to judge the relevance of objects from the task description given to them. This resulted in 20 separate conditions being shown to all the participants. These conditions are listed in Appendix IV along with a reference to the tests which they were used for.

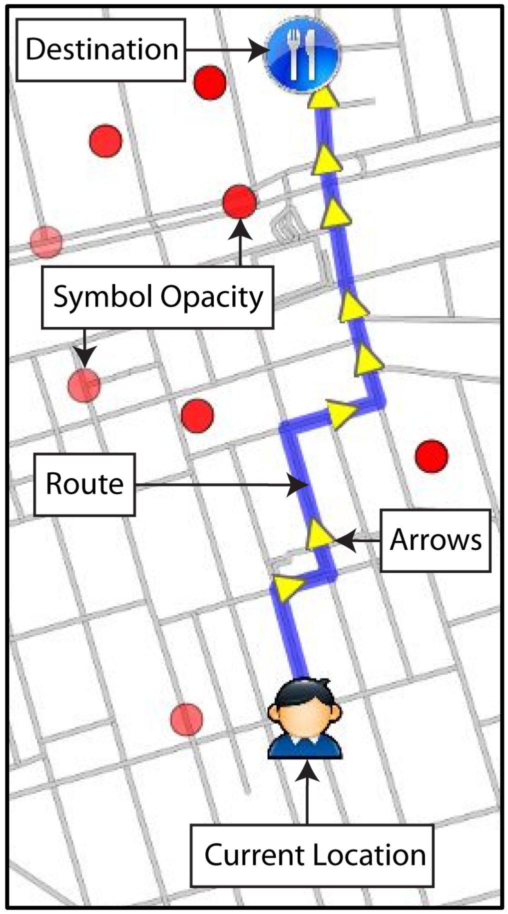


Figure 54 - The five visual elements studied to express spatio-temporal proximity in one sample display

Dependent Variables: As visual attention is guided by bottom-up information (stimulus-driven) and top-down (knowledge-driven) information several dependent variables were defined in order to capture the effects of both (Wolfe et al. 2003): response accuracy, confidence, and response time whilst eye tracking measured the time to first fixation of the most relevant object and the total fixation duration.

Response Accuracy – Accuracy is defined as the rank of geographic relevance of each map object. The response accuracy is 10 for selecting the map object ranked as the most relevant and 1 for selecting the object ranked as least relevant). For example, if a participant chooses the map object with the relevance rank of 8 (10 being most relevant, 1 being least relevant) then the accuracy will be measured as 8. The comparison is therefore on an ordinal level to test whether the subjects are selecting the most relevant object.

Response Time – Measures of the time taken to find a relevant object are used to measure the ability of the users to search for the most relevant object. The time begins when the stimulus is first shown and is halted when the user submits his or her choice by clicking on the 'Next' button on the interface. We assume a constant amount of time taken to take a decision and a constant amount to time for interaction during the choosing of the most relevant map object. The first assumption is based on decision making theory, as the decision complexity relates in part to the number of alternatives to compare, and all stimuli contain the same number of map objects to compare. The rationality of the second assumption comes from the invariant design of the interface design for each stimulus, which should result in any possible biases to interaction being minimised. The response time being measured therefore reflects that amount of time needed to comprehend the visual representation and then perform a visual search to find the most relevant map object.

Confidence – A confidence rating using a 5 point Likert scale – from 1 (not confident) to 5 (very confident) – was used to asses the effect from relationship explicitness on decision confidence.

Eye movements – Eye movements of participants were recorded during the experiment. For pre-defined areas of interest delineated for each stimulus at the location of the most relevant map object total fixation duration and time to first fixation were recorded to measure the time it took a participant to begin fixating the most relevant map object and the amount of attention that was directed towards this map object.

Based on the variables defined above, the null hypotheses can be defined in order for us to provide an answer to the research questions set out above:

> *H1: Encoding relevance as map symbol opacity has no effect on the perception of spatio-temporal proximity*
>
> *H2: An egocentric orientation has no effect on the perception of spatio-temporal proximity*
>
> *H3a: Explicitness of information has no effect on the perception of spatio-temporal proximity*
>
> *H3b: Routes and arrow elements have no effect on the perception of spatio-temporal proximity*
>
> *H3c: Adding arrow markers to routes has no effect on the perception of spatio-temporal proximity*

Participants: 32 students and employees from the University of Zurich agreed to take part in the experiment. However, 1 subject was excluded from analysis due to the inability of the eye tracking equipment to measure eye movements. The resulting 31 participants represent a mix of gender, age, nationalities, and educational background; although the location of recruitment meant that the participants were in general well educated. 61% of the participants had a geography background with the remaining 39% being made up of non-geographers. The educational background consisted of participants with a PhD (15%), MSc (71%), BSc (9%) or High School (5%) degree. The majority of the participants were male (65%).

Apparatus and Materials: The experiment took place in the eye tracking laboratory of the Geographic Information Visualization and Analysis group at the Department of Geography. The eye movement lab is equipped with an active, near-infrared enabled remote video eye tracker (Tobii X120). The experiment was run on a desktop computer with participants able to interact with a mouse and keyboard. The stimuli were created as static SVG maps within HTML web pages. These SVG maps were given the same dimension as an iPad screen (24cm x 18cm). The users were able to select map objects by clicking on them. Once selected, the objects turned from red to blue (see depiction in the scenario description below) in order to provide feedback to participants that they had successfully selected the object. A large button marked '*Submit'* was also placed at the bottom of the screen to allow participants to confirm their choice. The confidence rating interface was also implemented as a HTML web page. All response measurements were recorded in a XYZ database during the testing for later analysis.

Procedure: Participants were invited to the eye tracking laboratory of the Geographic Information Visualization and Analysis group at the Department of Geography. The eye tracker working with a near-infrared sensor was set to track and record with a sampling rate of 60Hz. The displays were shown to the participants on a 21-inch computer screen with a resolution of 1280x1024 pixels. The experimenter was present during the experiment run to explain and offer help with the software used during the experiment. The experiment was conducted in English although the written materials were also provided in German when required. All subjects signed a consent form and were given a brief explanation of the eye tracking procedure. Following this, the eye tracking equipment was calibrated to the participant and a short web form was then filled in by the participant, which allowed them to enter information about their gender, age, background, level of education, and familiarity with mobile and online maps.

As a next step participants were asked to read the task based on a scenario as shown on the following page. They were able to do this without any time limit and to ask any questions that they might have had. When the participant was ready, a test question was brought up and each participant was able to become familiar with the map interface, how to select an object from the map interface, and how to rate the confidence of the choice made. The process of answering a question was to first select what the participant believed to be the most relevant object and press the HTML button to submit the choice. This brought up a web page with the confidence rating interface so that the participant could then rate their confidence. Following this, they were then directed to the next question page. The participants were then asked to repeat this procedure a further two times using two more test questions. Once the test phase was finished, a web page was displayed to divide the test experiment from the main experiment. The main experiment consisted of 24 questions in total and therefore 24 measurements of accuracy, response time, and confidence. Examples of the scenario used can be found in Appendix V. The whole procedure lasted roughly 30 minutes. Refreshments were offered to participants at the end of the experiment.

7.3.2 Results Overview

Analysis of the responses was carried out in order to find statistical effects from varying the independent variable. The aim of these analyses was to isolate the various element types and discover the effect that they had on the dependent variables. I begin by looking into the effects of this *visual explicitness* upon the dependent variables that relate to the performance of the participants, and then follow this with a focus on the effects on the eye movement behaviour of the participants. The analytical approach taken was to first take all the stimuli and group them according to the elements of information that would be compared. This grouping of conditions and the process of testing is displayed below in Figure 55. The resulting groups were then organised into a hierarchy, so that comparisons on different levels of detail could be made. The aim of this process was to identify/isolate the elements of information that provided positive effects to the participant's responses. Additionally, this allowed the analysis to separately look into the effects of different elements. Statistics for each of the groups were created by first aggregating all the response measures for all conditions that make up a group, e.g. the mean of the 'With Opacity' group in the Opacity Test is the average of the responses from all subjects for all conditions where opacity is used as a visual element to encode geographic relevance. These values were then used in the subsequent tests for significance and descriptive statistics for the respective group. In total, three main tests were carried out so that the research questions described above could be convincingly answered. The first test (Opacity) aimed to study the effects of the encoding of relevance with the visual variable opacity (Research Question Q1), the second test (Orientation) looked into effect of orienting the map towards the direction of travel (Research Question Q2) and the following four tests (Explicitness Test 1-4) for the effect of spatial relationships explicitness (Research Question Q3a-c). The remainder of this section will describe the results of the statistical analysis for each dependent variable and divide each response measure sub-section into these six tests.

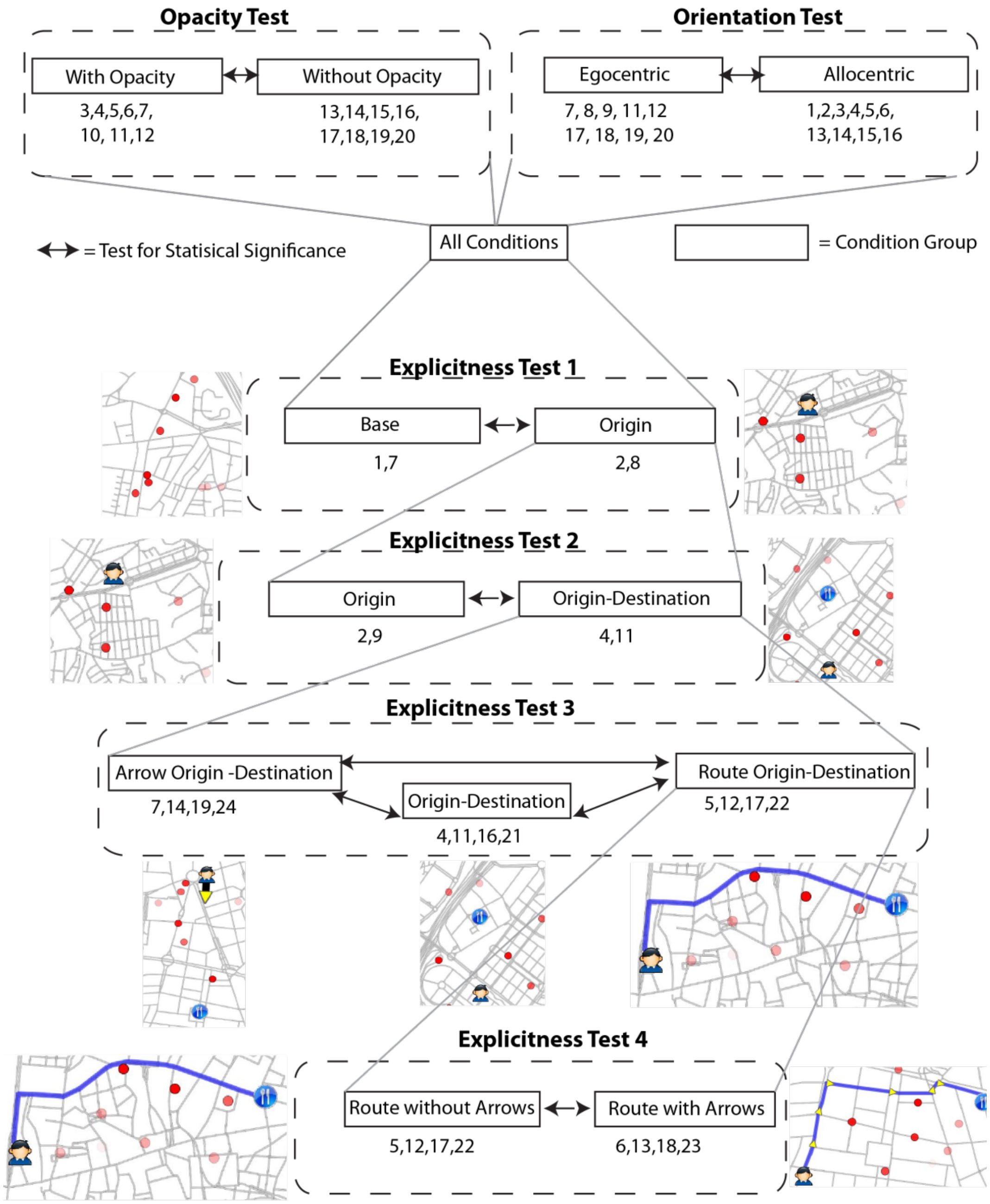


Figure 55 – Overview of analysis (numbers below each group refer to conditions included in that group).

7.3.3 Results - Opacity Test

Performance Measurements

Accuracy - The conditions with opacity encodings have a higher average accuracy (M=8.9 ± 0.3) compared to those conditions without opacity (M=8.7 ± 0.2). A dependent t-test showed that this difference is not significant (p=.08).

Response Time – Response time was affected by the presence or absence of opacity as encoding visual variable. The average response time was slightly lower with the presence of opacity (*M*=11.5 seconds ± 1.5) than with its absence (*M*=12.6 seconds ± 1.2), but the difference between the two groups is not significant (*p*=.41).

Confidence – The difference between the two groups for the confidence measurement is not significant (*p*=0.07). The average confidence for the opacity condition is *M*=4.09 ± 0.1, the one for the non-opacity group *M*=4.0 ± 0.1.

Eye Tracking Measurements

Time to First Fixation – The difference between the two groups for the time taken to first fixate the most relevant map object is highly significant (***p*=.008**). The use of opacity encoding allowed the participants to more quickly fixate the most relevant object (*M*=1.7 seconds ± 0.2) than in those conditions without opacity encoding (*M*= 2.5 seconds ± 0.3).

Total Fixation Duration – As with the time to first fixation the difference between the two groups for total fixation duration is highly significant (***p*=.002**). However, the difference was in the opposite direction, with the opacity group spending on average a greater amount of time fixating the map object (*M*= 2.3 seconds ± 0.2) than the group without opacity (*M*= 1.9 seconds ± 0.2).

Opacity – Results Summary

The results of this test have revealed several significant effects of incorporating opacity into the representation of geographic relevance associated with the efficiency of interaction (response time, time to first fixation, and total fixation duration). Confidence and accuracy of ratings, more associated with effectiveness, were both not affected by the presence or absence of opacity. Perhaps the most unsurprising finding is the ability of opacity to guide attention towards the most relevant areas of a map display. This ability can be observed with the Time to First Fixation statistic. In the opacity condition participants required on average a second less to first fixate the most relevant object.

Accuracy	Response Time	Confidence	Time To First Fixation	Total Fixation Duration
			**	**

Figure 56 - Significant differences for the Opacity Test (*=p<0.05, **=p<0.01)

7.3.4 Orientation Test

Performance Measurements

Accuracy – Egocentrically oriented map displays gave a mean accuracy of M=8.8 ± 0.1, whilst without orientation the accuracy was slightly lower (M=8.79 ± 0.1). This difference was found not to be statistically significant (p=.66).

Response Time – The effects of orientation on the response time was statistically significant (***p*=.028**). In the egocentric oriented map condition response times were slightly lower (M=12.5 seconds ± 0.7) than in the allocentric oriented map condition with an average response time of M=13.4 seconds ± 0.9.

Confidence – No clear statistical effect on confidence ratings was found between the two conditions (p=.53). This is expected to be the case as the descriptive statistics for the egocentric orientation group (M=3.73 ± 0.1) and allocentric orientation groups (M=3.74 ± 0.1) are very similar.

Eye Tracking Measurements

Time to First Fixation – The two groups showed significant differences (***p*=.018**). This difference favoured the egocentric group, with participants fixating on the most relevant point more rapidly (M=2.1 seconds ± 0.3) than for the allocentric group (M=3.4 seconds ± 0.2).

Total Fixation Duration - No significant difference was discovered for the average fixation duration (p=0.43) between the egocentric group (M=2.1 seconds ± 0.2) and the allocentric group (M=2.2 seconds ± 0.5).

Orientation – Results Summary

Overall, significant differences of map orientation were observable for response times and time to first fixations, with an egocentric map orientation producing better result on average. As with opacity, this means that an egocentric map orientation lends itself to the efficiency of the visual information seeking. From a cognitive perspective, this could result from the participants being able to more quickly recognise the route they had to take from start location to destination and therefore where the relevant objects might be located. Although this is a positive effect of an egocentric rotation, the other statistics suggest that the comprehension of the map was not improved with the map rotation.

Accuracy	Response Time	Confidence	Time To First Fixation	Total Fixation Duration
	*		*	

Figure 57 - Significant differences for the Orientation Test (*=p<0.05, **=p<0.01)

7.3.5 Explicitness Test 1

The aim of this test was to ascertain if representing the current location as described in the task (referred to as Origin in Figure 55) would alter the interactions with the map stimuli. This was the first step in the gradual exploration of the explicitness, with the Origin condition being compared with a baseline (referred to as Base in Figure 55) composed of conditions that only contained the map symbols encoded with the visual variable opacity.

Performance Measurements

Accuracy – In both conditions similar average accuracy of ratings were measured for the Base (M=8.1 ± 0.2) and the Origin (M=8.3 ± 0.2) and therefore no significant difference was observed.

Response Time – The responses were significantly faster (***p*=.004**) for the Origin condition group (M=14.3 seconds ± 1.2) in comparison to the Base group (M=20.6 seconds ± 1.8).

Confidence – Confidence ratings were significantly higher (***p*=.0001**) for the Origin condition group (M=2.7 ± 0.1) than for the Base condition group (M=1.7 ± 0.1).

Eye Tracking Measurements

Both conditions revealed no significant difference in average Time to First Fixation and Total Fixation Duration.

Summary – Explicitness Test 1

The results from this test show that including the origin only improved the confidence and speed of the responses. This suggests that participants mistakenly had more confidence in their relevance judgements. However, it must also be noted that the average confidence remained rather low (M=2.7) and therefore some uncertainty still remained as to whether the correct map object had been chosen. Overall, this test suggests that a greater level of explicitness is required in order for the participants to perform more efficiently and effectively.

Accuracy	Response Time	Confidence	Time To First Fixation	Total Fixation Duration
	**	**		

Figure 58 - Significant differences for the Explicitness Test 1 (*=p<0.05, **=p<0.01)

7.3.6 Explicitness Test 2

The second explicitness test takes the origin condition of Explicitness Test 1 and compares it to the origin-destination condition (referred to as Origin-Destination in Figure 55) that additionally contain the destination, therefore adding one more element of information to the stimuli. This allows the effect of the destination information element to be measured.

Performance Measurements

Accuracy – In the Origin-Destination condition (M=9.1 ± 0.1) subjects were significantly (***p*=.03**) more accurate than in the Origin condition (M=8.3 ± 0.2).

Response Time – The response time was slightly lower for the Origin condition (M=14.3 seconds ± 1.4) compared to the Origin-Destination condition (15.3 seconds ± 1.2). However, this difference is not statistically significant (p=.49).

Confidence – There was a significant increase in confidence ratings for the Origin Destination condition (M=3.9 ± 0.2) compared to the Origin condition (M=2.7 ± 0.1), (***p*=.0001**).

Eye Tracking Measurements

Time to First Fixation – Participants during the Origin condition spent less time for first fixation (M=2.4 seconds ± 0.3) than in the Origin-Destination condition (M=3.8 seconds ± 0.2). This was also statistically significant (***p*=.013**).

Total Fixation Duration – The total amount of time fixating on the most relevant object was significantly (***p*=.002**) lower in the Origin-Destination condition (M=1.4 ± 0.3) than in the Origin condition (M=2.6 ± 0.2).

Summary - Explicitness Test 2

The outcome from this test is that adding the destination has a significant impact on the response measures. Importantly, the increase in confidence is matched with an increase in accuracy; therefore the destination is improving the ability of the participants to understand the actual relevance of the map objects. Eye tracking results showed that although there was a greater delay before participants fixated on the most relevant object when the destination was present, it appeared that the total fixation time was shorter. This could mean that the increased information resulted in more distraction at first, with subjects first focusing on the destination object in order to relate this to the map objects. However, a better understanding of the relevance resulted in the need to concentrate less on these map objects.

Accuracy	Response Time	Confidence	Time To First Fixation	Total Fixation Duration
*		**	*	**

Figure 59 - Significant differences for the Explicit Test 2 (*=p<0.05, **=p<0.01)

7.3.7 Explicitness Test 3

The third explicitness test is performed with three condition groups, each group consisting of four conditions. Within each group, two conditions contain map objects with opacity encoding and two contain symbols without opacity encoding, allowing for more in depth analysis. For Explicitness Test 1 and 2 it was not possible to do this as relevance judgements using the Base and Origin destination groups were only possible when opacity was present. These three groups consist of a group that includes conditions containing the Origin-Destination, a second that includes conditions that contain the shortest route from Origin to Destination (Route Origin-Destination) and a third group that contains a directional arrow along the route (Arrow Origin-Destination). This test aims to discover if these additional pieces of information help the user interpret the relevance of the map objects in the map displays more effectively and efficiently.

Performance Measurements

Accuracy – The most accurate responses were provided by the Route group (M=9.4 ± 0.2), followed by Route Origin-Destination (M=9.1 ± 0.1) and Arrow Origin-Destination (M=9.1 ± 0.1). This overall difference was found to be statistically significant in an ANOVA (***p*=.02**). A multiple comparison showed that this difference was between the Route Origin-Destination condition and the two other conditions (Route Origin Destination vs. Origin Destination p=.004, Route Origin-Destination vs. Arrow Origin Destination p=.03).

Response Time – No significant effect was found within the response time observations for the three groups, with an ANOVA resulting in a p=.07. The Arrow Origin-Destination group contained the lowest average response time (M=10.6 seconds ± 0.6), the Route Origin-

Destination group the second lowest (*M*=11.3 ± 1.1) and Origin-Destination the slowest response time (*M*=13.9 ± 1.0).

Confidence – Confidence was significantly affected by the different conditions (***p*=.0016**). The Origin-Destination group average was the same as the Arrow Origin-Destination Group (*M*=4.1 ± 0.1). However, the Route Origin-Destination group had the best average confidence rating (*M*=4.6 ± 0.1). A multiple comparison found that the significant difference lay between the Route Origin-Destination group and the two other groups (Arrow Origin-Destination ◎ Route Origin-Destination ***p*=.005**, Route Origin-Destination ◎ Origin-Destination ***p*=.005**).

Eye Tracking Measurements

Time to First Fixation – The Route Origin-Destination condition allowed the subjects to most quickly fixate on the most relevant location (*M*=1.2 seconds ± 0.3), followed by the Arrow Origin-Destination condition (*M*=1.6 seconds ± 0.1) and lastly Origin-Destination (*M*=2.6 seconds ± 0.3). These differences were found to be statistically significant (***p*=.019**). Multiple Comparison found that the difference lay between the Origin-Destination group and the two other groups that contained more explicit information (Arrow Origin- Destination ◎ Origin-Destination ***p*=.0004**, Route Origin-Destination ◎ Origin-Destination ***p*=.0005**).

Total Fixation Duration – An ANOVA showed that a statistically significant difference exists between the groups for average total fixation duration (***p*=.038**). The group with the shortest average total fixation duration was the Origin-Destination group (*M*=1.7 seconds ± 0.2) followed by the Arrow Origin-Destination group (*M*=2.1 seconds ± 0.2) and the Route Origin-Destination group (*M*=2.5 seconds ± 0.2).

Summary - Explicitness Test 3

The main findings within this test relate to both the performance and eye tracking measurements of accuracy, response time, time to first fixation and total fixation duration. Of the entire conditions group, the Route Origin-Destination group proved to be the better. It resulted in more accurate ratings, better confidence in the ratings and also guided the attention more quickly to the most relevant object. However, as with the Arrow Origin-Destination condition, more information resulted in the need for a longer time focusing on the most relevant object. But as this did not affect the response times negatively, it is perhaps a necessary cost in order to gain a more effective judgement of what is relevant. In this test, it seems that more information resulted in longer times fixating the most relevant map object, but less time before the participants was able to first fixate the most relevant object. This level of explicitness suggests that the better understanding is helping the participants find the relevant areas more quickly, but possibly results in a more thorough visual search based on this additional information.

Accuracy	Response Time	Confidence	Time To First Fixation	Total Fixation Duration
*		**	*	*

Figure 60 - Significant differences for the Explicit Test 2 (*=p<0.05, **=p<0.01)

7.3.8 Explicitness Test 4

The final explicitness test takes the Route Origin-Destination condition from Explicitness Test 3 and attempts to make a more detailed assessment of how routes can be represented. The two conditions that are compared are composed of conditions with a route *with* direction arrows (Route with Arrows) and a route *without* direction arrows (Route without Arrows). The aim is to find if these directional arrows make any difference to the responses of the participants.

Performance Measurements

Accuracy – The average accuracy for both conditions was almost the same, Route without Arrows (M=9.4 ± 0.1) and Route with Arrows (M=9.3 ± 0.1) and therefore no effect on accuracy was measured.

Response Time – A difference of 1 second was found to exist in the average response times between the two groups, Route without Arrows (M=11.7 seconds ± 1.1 and Route with Arrows (M=12.5 seconds ± 1.1). However this difference is not significant (p=.26).

Confidence – The average confidence ratings for both groups were similar, Route without Arrows (M=4.6 ± 0.1) and Route with Arrows (M=4.4 ± 0.1) and therefore no difference in confidence was observed.

Eye Tracking Measurements

Time To First Fixation – No significant difference was observed between the two groups (p=.13) as only a small difference was observed between the Route without Arrows condition (M=1.2 seconds ± 0.2) and the Route with Arrows condition (M=1.5 ± 0.2).

Total Fixation Duration – Again, no significant difference was observed between the two groups (p=.07) as only a small difference was observed between the Route without Arrows condition (M=2.4 seconds ± 0.2) and the Route with Arrows condition (M=2.5 seconds ± 0.2).

Summary - Explicitness Test 4

The main finding from this test is that adding arrows to the routes did not alter the ability of the participants to discover the most relevant map object more quickly or accurately and their eye movements were also not altered by this factor. This means that no difference could be measured between the two condition groups and therefore this additional information adds nothing to the effectiveness or efficiency of the visual search process.

7.3.9 Summary of results for experiment III

In this section we revisit null hypotheses and discuss which of them can be rejected based on the experimental results reported in the previous sections.

H1: Encoding relevance as map symbol opacity has no effect on the perception of spatio-temporal proximity

The results of the Opacity Test allow the rejection as several statistically significant differences were discovered. The most profound effect was found within the eye movement analyses. The attention of the participants was being directed towards the most relevant object on the map display. This result corroborates the findings by (Reichenbacher 2007) who also found opacity being able to guide attention. The results suggest that the main influence of opacity is on the stimulus driven visual attention, as the performance measures were not significantly different between the two condition groups.

H2: An egocentric orientation has no effect on the perception of spatio-temporal proximity

The outcome of the Orientation Test found statistically significant differences in both performance and eye tracking measures of the participants. Hence this null hypothesis can be clearly rejected. These differences were in the time it took the subjects to first fixate on the most relevant map object and then choose a relevant map object. While this has some value, the accuracy and confidence ratings were not affected by the orientation of the map and these two statistics are arguably more important for these assessments.

The ability of the egocentric orientation to direct attention to the most relevant objects can perhaps be explained by two areas of past research. Navigation studies have previously tested out the use of ego-centric map orientations through actual navigation tasks (Hermann et al. 2003, Winter and Tomko 2004). The automatic orientation of the map to the direction of travel is believed to support navigation through alleviating the necessary mental rotation by the navigator. This suggests that the participants of these studies can intuitively link locations higher up on the display with those locations physically located in front of them. From an image schema perspective, the participants can link the up-down image schema of the map space to the front-back image schema of the environment, where *up=front* and *down=back*. As the given task requires the participant to move in the direction of the destination, it is possible that this same process allows the participants to quickly perceive the map objects 'in front of' them, but which are further *up* the map display.

H3a: Explicitness of information has no effect on the perception of spatio-temporal proximity

This null hypothesis can be resoundingly rejected as all the measurements of Explicit Test 1 were found to be significant. Several statistically significant differences were observed between different levels of explicitness, with a general trend being particularly apparent for the performance measures, which can be seen in Figure 61**Error! Reference source not found.**. From a general perspective, the accuracy and confidence increase with increasing explicitness, whilst the response times decrease. However, the relationship is not linear, and two important conclusions can be drawn from the graphs depicted in Figure 61**Error! Reference source not found.**. The first is that at some point the extra explicitness does not result in better performance measures, as can be seen in the final test of explicitness (Explicitness Test 4) with the addition of arrows to the route. The second is that an increase in explicitness did not always result in statistically significant increases for all the performance measures, and therefore the exact relationship between explicitness and these performance measures is perhaps a complex one.

The eye tracking measures in Figure 61 how various interesting trends. The Total Fixation Duration measure has a U shaped trend line. If taken as a measure of cognitive effort, then one possible inference is that the less explicit conditions require more attention in order to decode what the stimuli show and to judge the relevance. The middle explicitness condition of Origin-Destination reaches a level where the visual stimulus is more easily understood, and at the same time still contains relatively little extra information. Once more information is added then the participants can relate the map objects to more than just the Origin and Destination, and therefore more attention is again focused on the extra visual elements. The least explicit condition guides the attention of the user quickly to the most relevant object with the opacity visual variable. However, as more information is added, the attention is distracted first to these other objects, which can be related to the map objects in order to decide which map objects are the most relevant. The route element of information again causes a dip in the time it takes to fixate on the relevant location, which suggests that the attention is being guided from a knowledge driven process that allows a quick appreciation of where the more relevant map objects might be located.

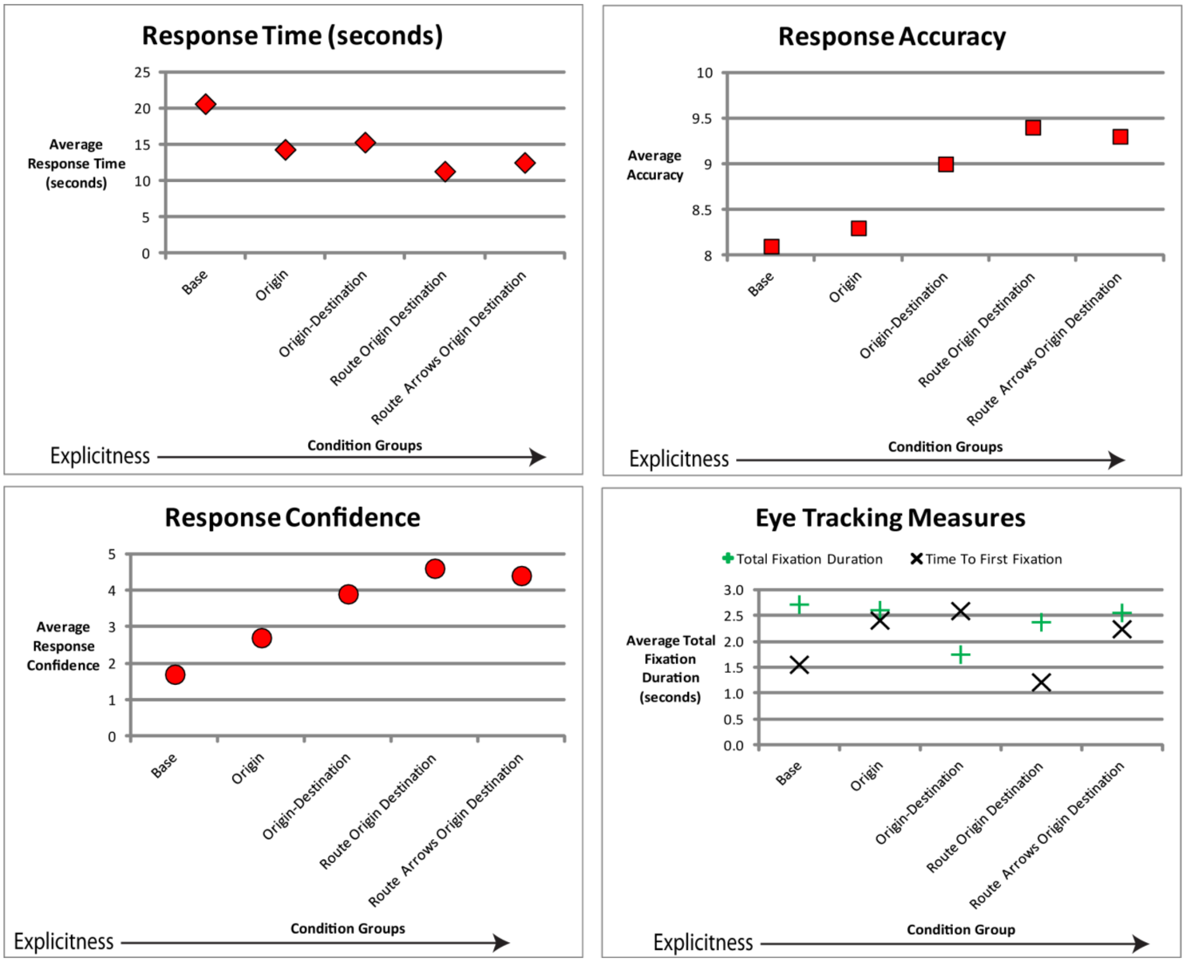


Figure 61 – Effect of explicitness on performance and eye tracking measures

H3b: Routes and arrow elements have no effect on the perception of spatio-temporal proximity

Explicitness Test 3 relates to the above hypothesis, and its results allow us to reject this hypothesis. This test focused on three different methods to represent a route and to see if this has an effect on the perception of spatio-temporal proximity. The main effect was on the response time and accuracy of the participants. The most successful method from a performance perspective was to place an origin and destination symbol on the map display and a shortest route between these two symbols. The accuracy and the confidence of the relevance judgments were then increased to a statistically significant degree. Participants also were found to more quickly fixate on the most relevant map object, with the extra information most likely guiding the participant's visual attention. However, this extra information resulted in an extra cognitive cost as more time was spent fixating on the map objects. This could as well be a result of the map objects being more thoroughly compared, and this would be the reason for the increased accuracy.

H3c: Adding arrow markers to routes has no effect on the perception of spatio-temporal proximity

This hypothesis came from research by (Tversky and Lee 1999), who discovered that in sketching a route, people commonly add arrows along the route. Research in diagrammatic reasoning has also tried to explain the use of arrows within diagrams and how they can represent direction (Tversky et al. 2000). However, this hypothesis could not be rejected, because none of the observed differences was statistically significant. This suggests that adding arrows to the routes makes little difference to the perception of spatio-temporal proximity. As theory suggests that the amount of information in an interface should be minimised where possible, this finding implies that if routes are included in a map display then arrow markers do not need to be added to them. However, there may be some cases where this would not be the case. As the conditions in this experiment were static, the origin and destination were always in view. Interactive maps that can be zoomed and panned do not guarantee this, and therefore the markers may add helpful information when the origin and destination are no longer within the map extents.

Chapter 8 Discussion

The work carried out in this thesis attempts to describe and evaluate a set of methodologies for designing visual representations of geographic relevance. An overall finding in agreement with Freksa et al.(2005) is that context and cognition are strongly associated with the use of representations, and that representations can only be properly understood in conjunction with both of these factors. The aim of this chapter is to discuss the findings that this research has produced, examine how they fit to other research results, and what new knowledge can be learnt from them. Section 8.1 in this chapter will revisit the research questions and explain how the work described answers the questions originally defined in the first chapter of this thesis. The structure of the following section will be based around the conceptual framework, in order to explore the findings in the full context of the subject areas that this thesis impact upon. Furthermore, the findings from the empirical evaluations are also discussed in order to provide a full account of the work carried out in the past chapters.

8.1 Revisiting Research Questions

The work in this thesis was directed towards the provision of answers to seven research questions. In the following these research questions are listed again with corresponding answers.

RQ1 - How can relevance assessed datasets be effectively filtered in order to support spatio-temporal plans and actions?

The research question was answered through the application of contextual analyses that could predict what is accessible to an information seeker, and allow the creation of activity schedules which are automatically constrained to the activity of the information seeker. The filtering took place during the planning of these schedules, but was also incorporated during the amendments to these planned schedules that may be necessary whilst they are being acted out. Also discussed were three methods of presenting the result set remaining after the spatio-temporal filtering has taken place which consisted of either presenting all the objects, chunks of them or only a single object. The method selected depends on the context of the user, such as the type of information seeking behaviour that should be supported. Planners will most likely perform semi-directed information seeking, where goals are not yet clearly defined regarding exactly where and when something will be performed, and the individual will therefore need to make decisions regarding this. Limiting the number of objects that they need to compare is required, and a chunk approach is recommended. Acting requires the re-scheduling of a chosen action based on the current time and location, and thus the individual possesses clearer goals, which suggest directed browsing behaviours. As the situation is also more time pressured in which to make a decision, the approach recommended is to display a single object to avoid large numbers of comparisons to become necessary.

RQ2 - Which cognitive and contextual factors should guide the design of visual representations of geographic relevance?

The contextual and cognitive factors used to design the visual representations of geographic relevance were sourced from literature. Space-time and activity were highlighted as key constituents to a mobile information seekers context and explored in Chapter 4, whilst the cognitive processes, tasks, and structures were incorporated into the methods described in Chapter 5 and 6. Combining both of these factors into the development of the representations allowed two important types of constraints to be supported. The first type was the contextual spatio-temporal constraints that aided the user's perception of the spatio-temporal accessibility. The second type relates to the limited resources of human cognition and was supported by developing representations that offload cognition from the human to the representation, through the adaptation to the relevance criteria and the design of novel interactional methods.

RQ3 - Which categorisation methods are appropriate for classifying geographic relevance values?

It was proposed that categorisation of relevance should not solely rely on traditional cartographic methods of categorisation, which aim to visualise the statistical distribution of the data accurately. Instead, they can also be directed to the narrowing down of the search space, and applied in the development of interaction tools that allow the movement from an overview representation to a more detailed view. The approach taken was to first define categorisations for each relevance criterion, and label them to communicate how these criteria are commonly understood. The raw relevance values were also categorised, using an exponential function that can assign few very relevant objects to the highly relevant categories and large numbers of less relevant objects to the lower categories. This then allows the information seekers to narrow down the search space rapidly, and concentrate their decision on only the most relevant objects.

RQ4 - How can metaphors be developed to communicate and interact with relevance?

Linguistic metaphors of relevance, taken from literature sources, were found to be based around the image schema SCALE, and the popularity of each metaphor was investigated through the analysis of search engine results and micro-blogs. It was found that the common way to describe the degree of relevance was through the use of linguistic hedges. Visual metaphors were developed by first defining cognitive structures from image schema and basic domains that fitted to the characteristics of relevance, and then creating map symbols that contained these cognitive structures. The interaction metaphor of relevance zooming was based on past methods of 'zooming' spatial information but applied to relevance assessed datasets and allowed the rapid narrowing down of a search space through the application of semantic, physical and content zooming.

RQ5 - Which visual variables offer an intuitive representation of relevance?

Experiment I explored the ability of colour saturation, colour value, and opacity to represent geographic relevance intuitively. The experiment involved participants ranking map objects based on these visual variables but without them being explicitly told how these visual variables were related to relevance. The perceived ranking of these map objects was compared to their actual relevance, and it was found that three of these visual variables were able to offer intuitive mappings to relevance, with all variables showing correlations of over 0.7 between the perceived and actual relevance ranks of map objects. However, opacity proved most intuitive of the three visual variables tested, with a correlation of over 0.9.

RQ6 - Can visual metaphors of relevance provide intuitive mappings to geographic relevance?

Evidence from Experiment II strongly suggests that visual metaphors can provide intuitive mappings of geographic relevance and, as such support the comprehension of geographic relevance. However, there was a large variance between all the metaphors tested, and therefore the use of a metaphor should be carefully considered and requires evaluation to ascertain if the mapping of the phenomena to be represented is functioning. Particular success was found with the full-empty metaphor, which proved to be most easily recognised by participants, and also provided the most intuitive mapping of geographic relevance.

RQ7 - Do explicit visual representations of spatial relationships improve the intuitiveness of geographic relevance?

The answer to this research question is that increasing the explicitness of representations of geographic relevance does increase the intuitiveness of relevance. The participants were able to more accurately, confidently, and rapidly discover the most relevant object when the map displays were more explicitly designed. Eye movement behaviour also suggested this was the case, but the relationship to increasing explicitness was less monotonic than for the traditional performance metrics.

8.2 Context Domain

Research documented in this thesis demonstrated the utility of context to help define what a map should and should not contain. This is however not a new approach, but rather extends a large body of research that has already come to this conclusion (Reichenbacher 2003, Dey 2001).

The main application of the contextual domain was discussed in Chapter 4, with the utility of context coming from the ability to automatically filter relevance assessed data based on an individual's spatio-temporal constraints. Based on the definition of context by Nivala and Sarjakoski (2003a), the types of context explored were location, time and user activity. When relating this work to previous research on the contextual adaptation of mobile maps by Reichenbacher (2004), it is clearly focused on the adaptation of the amount and level of detail through filtering geographic information. Although not specifically aimed at the generalisation of the cartographic representation, the methods presented could also be applied in such a setting. Specifically, they would offer a means to inform the generalisation operator of selection, and decide which map objects to display and which to remove (Edwardes et al. 2005, Sarjakoski et al. 2005).

The other area impacted by this work is upon the filtering of data, as current commercial systems frequently utilise a simple 'Search Around Me' mechanism that filters objects based on a set distance (Raper 2007), but this method of filtering data does not accurately represent the true constraints of a user. Its commonality is more likely an artefact of the ease of implementation. Such a simple filter has the danger of providing information about places that are inaccessible (false positive) or not providing information about a potentially relevant place that is accessible (false negative). The spatio-temporal constraints are an improvement as they offer a closer link between the utility offered to an individual by the real world places, as inaccessible places hold no utility at all (De Sabbata and Reichenbacher 2012). These places and the information related to them can therefore be filtered away from the results returned. Furthermore, simple distance-based filtering mechanisms contradict the opinions of Raubal et al. (2004) which are that mobile systems should aim to more accurately fit to the nature of everyday spatio-temporal activities, within which spatio-temporal constraints play an important role. User studies have also shown that filtering data based on spatio-temporal accessibility is desirable to mobile information seekers (Mountain and MacFarlane 2007, De Sabbata and Reichenbacher 2012). Although filtering data based on the spatio-temporal accessibility has already been discussed by Bereuter et al. (2009) and implemented by Espeter and Raubal (2009), until now, no commercial mobile systems incorporate these mechanisms for several possible reasons. The first reason, in the opinion of Neutens (2011), is a technical one. There exists a lack of open source data and code for spatio-temporal activity analysis, and this makes adoption rather difficult. The second reason is a more people centred one – in the opinion of Miller (2004). Time geographers should partner with LBS providers in order to support spatio-temporal queries. They may also be able to collect useful data about space-time activities that could benefit their own research.

Aside from the spatio-temporal perspective on context, activity was also utilised within this thesis to design contextual analyses using the framework of activity theory. Several past studies have discussed this theory in relation to the support of spatial tasks with mobile systems, for example (Huang and Gartner 2008, Cai and Xue 2006, Dransch 2005). However, whilst this work focused exclusively on activity, the main analytical methods of context applied in this thesis was provided by space-time. What was demonstrated is that the hierarchical structure postulated by activity theorists provides an excellent representation of an individual's constraints for the analysis of an activity. The constraint model is able to represent constraints at different levels of an activity, from activity as whole to each constituent actions (stays) and travel sub-actions. This combination of space, time, and activity has already been proposed as of significant value by Miller (2004) and it allows three of the primary contextual elements proposed by (Dey and Abowd 2000) to be incorporated into one framework - time, place, and activity. However, the novelty of the framework presented in this thesis was in the recognition that an activity consist of planning and acting phases, and that it was necessary to also support the information seeking of the individual during both phases. Previous work has treated the development of planning as a single task (Seifert et al. 2007, Abdalla and Frank 2011). Whilst this is an important area of study, it must also be acknowledged that these plans are acted out and, when contexts then change, the plans become unworkable. Therefore both situations should also be considered and how representations can be made adaptable to these unforeseen contexts. Furthermore, general support can be found for this contention within the original work on geographic relevance by Raper (2007), which differentiated between information needs related to tasks taking place at the current location and time, and information needs related to future tasks. This division also manifests itself within the discussions of several research papers dealing with mobile information seeking (Sohn et al. 2008, Amin et al. 2009). Work on the cognition of space has also tried to explain spatial behaviour as taking place within a conceptual space that consists of planning where, when, and what to do, as well as the actions that result from this which take place in physical space (Kitchin 1994). For mobile geographic information seeking, it is probable that acting or planning could become an important element of context, which could be exploited, and could decide how information is represented and interacted with. Agreement for this can be found in (Ricci et al. 2002), who recommend that the acting out of a travel plan requires simplified interaction mechanisms to support ad-hoc querying on mobile systems. User studies have also shown that acting and planning require different map scales, with large map scales required when acting and small scales for planning (Nivala et al. 2008). Furthermore, an important consequence of the planning phase of an activity is that it is very conceivable that the individual information seeker will not necessarily be mobile whilst forming the plans, but likely have access a desktop computer. This results in the finding that geographic relevance does not have value only for the development of location based services for mobile people, as it was originally intended but also for stationary desktop use of geographic information. If this is the case, then it can be said that geographic relevance is applicable to not just systems that exploit the actual location of an information seeker, but in the words of Amin (2009), in a broader context when an individual searches for a relevant *"business or place of interest that is tied to a specific geographical location."* This will also have a notable effect upon the type of relevance criteria that are applicable to the information seeker, and also the weightings that should be placed upon these criteria during the process of combining them.

8.3 Cognitive Domain

The findings of this thesis support the proposal by Raubal (2009) and Mei and Li, (2008), that the overall value of employing cognitive approaches is in the improvement of a system's usability. For location based services and mobile services, usability has been highlighted as an important factor in stimulating their uptake (Navratil and Grum 2007, Malaka and Zipf 2000). Moreover, evidence can be found in this thesis that the cognitive domain also offers means in which the communicational aspects of the visual representation used by mobile systems can be incorporated and evaluated (Raper et al. 2002).

The cognitive domain is first explored in Chapter 5, with the use of external cognition to discover methods of designing interfaces and the evaluation of the representation through the employment of a simple cognitive architecture (CogTool) and a model of visual clutter. However, the cognitive domain does not only offer a method through which to inform the designs of representation, but also offers a means by which these designs can be quickly evaluated (John et al. 2004). Utilising both aspects impacts the efficiency of designing systems twofold. Theories of cognition allow the design to be oriented in a direction that will more likely result in it being usable, without the need to prototype several different designs by gradually narrowing down the search space through iterative usability testing (John and Jastrzembski 2010). The search for a 'good' design is more accurately targeted to a region of this search space that represents usable designs. The second gain in efficiency is through the employment of cognitive architectures, such as CogTool, to allow initial testing to be carried out rapidly. This again narrows down the search space further and leads the way to subject testing, which despite of being more costly results in more definitive answers to design questions.

Apart from the benefit to the designer, this approach is also of great value to the user, as the service or system becomes more usable. The approach can attempt to answer a basic question and decide which elements of the map are important, and should be made apparent to the perception of the individual (Habel 2003). It is the relevance criteria that influence how the map should communicate GR to the individual information seeker, and what tasks it must be able to support. Supporting these tasks is then carried out through the offloading of cognition, which is a key component of the method described. It was observed that offloading often leads to the necessity for some form of spatial analysis to be carried out. For example, communicating the direction of travel involved drawing a route, which required route analysis, or creating density surfaces was necessary to communicate co-location to visualise densely populated areas of related objects. This can therefore be conceptualised as equivalent to ideas proposed in the theory of distributed cognition, which treats cognition more loosely as a form of computation that is distributed between people and media (Hutchins 2000). A similar idea is also the division proposed by Norman (1991) of a knowledge in the head, and a knowledge in the world. These analyses then enhance the perceptions through the addition of extra information. The representation of geographic relevance therefore requires something similar to visual analytics, where the representation is designed to enhance the human perception of patterns within the data (Fabrikant and Lobben 2009). However, such an approach would need to appreciate the context of mobile use, which involves limited screen size and cognitive resources (Nivala and Sarjakoski 2003b). The incorporation of cognitive theory also plays another important role aside from computational offloading - to aid the interpretation of the representation so that the individual understands why the map objects are relevant. This then aids the knowledge driven element of the visual attention, which plays an important role in the perception of geographic relevance (Swienty et al. 2008b).

In addition to the work related to external cognition, Chapter 6 also provided findings relating to the cognitive structures of image schema and basic domains. These structures were utilised in the study of linguistic metaphors and development of visual metaphors of geographic relevance. Analysis of the linguistic expressions of relevance degrees suggested that hedging is a very common means to express the quantity of relevance. This agrees with Clausner and Croft (1999) who describe the use of hedges (more, less, very) as being a core characteristic in the linguistic description of quantities. Also frequently used were the terms associated with height, e.g. highly relevant. Clausner and Croft (1999) state that this has an experiential basis, as adding more of something to a pile increases its height, which results in an increase in height being analogous to an increase in quantity. The commonality of this metaphor can also be seen in the visual metaphor employed by search engines to represent the ordinal relevance of documents, with the more relevant results positioned at the top of the result list. Furthermore, these results also feed back into the theory of image schema, since they provide evidence for a common concept lying behind the communication of relevance. This evidence comes from the observation that relevance is mostly communicated using monoscalar antonyms, all of which share a single structure that fits well to the SCALE image schema described by (Lakoff and Johnson 1980).

The development of visual metaphors was partly based on the initial linguistic analyses, but also incorporated basic domains and image schemas. It extends the original work by

Reichenbacher (2005b) through the specification of a method to discover and design metaphors and through the setting out of new metaphors for geographic relevance. A similar design process is proposed by MacEachren (1995), who links the use of colour to image schema, with light and dark colours being related to front-back image schemas. The overall aim of this process was to allow the user of the metaphor to recognise the connection between the source and target domains, and then correctly mapping one to the other. If this process fails then so will the metaphor (Hamilton 2000). However, if it is carried out successfully it enforces the cognitive link between the perception of the map interface and knowledge of what the map means and which areas of it are relevant (Couclelis 1998). Although the advice of Erickson (1990) for metaphor development is to define what needs to be communicated and then to find and develop a metaphor based on real world events, objects or institutions, the design process taken in Chapter 6 differed as an intermediate step was introduced. The nature of what should be communicated by relevance was first described but then the definition of cognitive structures that can communicate the properties of relevance was carried out next. Only then were visual metaphors developed from the cognitive structures. One important advantage of this approach is that it simplifies the process of discovering suitable metaphors, as these structures offer inspiration at to what a good metaphor might be, which can often be a difficult task in itself (Vaananen and Schmidt 1994). Furthermore, this approach finds agreement within the work Hurtienne and Blessing (2007) and Kuhn (Kuhn 1991) who found that cognitive structures, such as image schema, offer a powerful means in which to build intuitiveness in the design of graphical interfaces. Further agreement can be found in the work by Ziemkiewicz and Kosara (2008) who find that visual metaphors help the design to be more closely aligned to the mental model of a user, something that cartographers have long highlighted as playing an important role in the success of a map (Kolány 1969). However, a study by Sutcliffe et al. (2000) investigating the use of visual metaphors in seeking information discovered that even when metaphors are recognised and mapped correctly, they can also change the information seeking process itself, which can then also lead to a sub-optimal performance. To find if this is also the case for geographic relevance would require an empirical study focused on this answering this question, although the results of experiment II discussed in the following section suggest that this may not be the case.

8.4 Representational Domain

The methods for representing GR developed in this thesis went beyond previous research, which mainly concentrated on employing and evaluating visual variables for encoding relevance as map symbols (Reichenbacher and Swienty 2007, Swienty et al. 2008b, Kiefer et al.

2012). Instead they looked to identify and add information that could aid the interpretation of the geographic relevance of map objects. This process of designing representations showed geographic relevance to be a complex phenomenon to represent, especially at the conceptual level. This complexity comes in part from the dynamism of a mobile user's context, as this context influences the spatial qualities of the environment that relate to the relevance. As stated by Couclelis (1993), the intentions and purposes of an individual affect the conceptualisation of a phenomenon, and therefore the dynamic context and changing goal of a mobile user result in the conceptualisation of relevance also being dynamic. This then results in the most basic division during the conceptualisation of spatial phenomena, object or field, being both applicable to the representation in different contexts (Peuquet 2002). Geographic relevance is therefore a phenomenon that can be conceptualised from multiple viewpoints, as its membership to the parameters specified by Bian (2007) that dictate whether a concept is more object or field-like, will often differ according to the context. Furthermore, this dynamic context also impacts on the vagueness associated with its conception. This vagueness results in part from the uncertainties in the spatial location of the boundaries that result from the calculation and prediction of relevant areas, as seen with space-time accessibility or co-location. Therefore this vagueness relates to the mode of observation and measurement, according to the typology of Couclelis (2003). Also, as this vagueness stems from uncertainty, the communication of this vagueness was carried out by using graphical means related to uncertainty, such as focus, which have recently been proposed to effectively communicate uncertainty (MacEachren 1992, MacEachren et al. 2012).

During the design process described in Chapter 5, it became clear that the design of map representations that must communicate relevance criteria is complex, in comparison to the typical design of an interface used by typical search engines. The simplicity of communicating the relevance of information objects in search engines in part relates to the information objects possessing no spatial component. This allows traditional information retrieval systems to communicate the relevance of these information objects through their spatial positioning, commonly through the application of a "more is higher up, less is lower down" metaphor. For map objects displayed in map space, this will never be an option, as their spatial position holds intrinsic meaning to the information seeker. This is true for their absolute position, as well as for the relative positioning of the map objects, which also holds meaning for the representation of relevance as it enables the perception of relations and patterns (Rescorla 2008). The spatial concepts underlying these patterns represent relatively complex forms of geographic knowledge, such as cluster or co-location, and therefore require some basic tenets of geographic knowledge to be able to interpret them (Golledge et al. 2008). Ideally, this knowledge should be communicated instantly and understandably and require little additional explanation (Keller and Keller 1993). In some cases representing these relevance criteria could then be complicated by the naivety of the individual information seeker. This could result in implementations of relevance representations based only on conceptions of spatial patterns held by experts, which differ to those conceptions held by naive users. This danger has been long acknowledged as a natural component to the relationship between the producer of a representation and the consumer of that representation (Meine 1977), but it still remains far from being effectively understood despite attempts to formalise the aspects of this relationship (Frank 2000). An example in the context of this thesis would be the conception of a cluster - how many objects does it consist of? How far away must the objects be from one another to be considered to be part of a cluster? Very likely these parameters will deviate between individuals and result in a cluster being visually represented on the map that to some users may not be considered as a cluster. A mismatch in conceptions would then either misinform or confuse the user, and stem from the basic understanding that maps and representations of space are not perfectly analogous to the real world phenomena that they aim to represent (Barkowsky and Freksa 1997). As geographic relevance is a mental concept, it is likely that it will be susceptible to this type of mismatch on a conceptual level.

Additionally, the application of external cognition suggests that it is also not always advantageous to exactly match an individual's internal conception of a relevance criterion to its external representation, even though this is often described as the goal of a visual representation (Keller and Keller 1993, Woods 1991, Edwardes 2009). An example of this can be seen in the representation of the relevance criterion cluster in Chapter 5, as a cluster is most commonly conceptualised as a spatial region. However, visualising these spatial regions could lead to incorrect inferences as the size of a region will most likely be incorrectly related to relevance, which for clusters is often not the case as the relevance results from the density of objects. This means that possible biases during the interpretation of the relevance of a cluster alter dependent from how it is represented, and requires the visual representation to differ from the conception of the relevance criterion. The approach taken therefore addresses the representation of relevance with the aim, in the words of Simon (1969), "*to make the solution transparent*".

Apart from visual representations, interaction with relevance assessed datasets was also studied. Interaction designs described in this thesis were relevance zoom and faceted search. The implementations described both support an important task for visual information seeking, i.e. to move from an overview to a detailed view (Shneiderman 1996). As defined by Timpf (1999), the level of detail can be amended through aggregation, generalisation, and filtering, and both of these methods use a filtering approach. However, there are differences in the form of interaction used, and how they both use the relevance values of the objects. The interaction necessary for the relevance zooming requires fewer interactions to move from overview to detail, and can therefore be termed more efficient according to the opinion of Oviatt (1997). The zooming is carried out through a single interaction with an interface element, whilst faceted search requires several interactions through a hierarchically organised menu. However the advantage of the faceted search will be during the navigation process, as the progressive setting of thresholds provides the information seeker with a clearer understanding of why the remaining objects are relevant to them. Therefore a trade-off exists, as the automation of relevance zooming removes the knowledge describing how the information seeker navigated to the subset of relevant objects. It is possible that this will lead to a greater feeling of control over the navigation process, which is theorised as a contributing factor to usability (Shneiderman 1989). In time pressured or distraction rich situations the increased amount of interaction may of course produce the opposite effect on usability (Oinas-Kukkinen and Kurkela 2003), and thus relevance zooming would become more applicable. As acknowledged by (Cartwright et al. 2001), the correct interaction technique is dependent upon the user and the activity of that user, and for relevance this is most clearly also the case.

Also making a clear impact on the representational domain are the results of the three experiments described in Chapter 7. In Experiment I the main contribution is to the study of map semiotics and cartographic theory with regard to the application of visual variables to the encoding of information in map symbols (Bertin 1983). Experiment I attempted to extend the past work by measuring the intuitiveness of the mapping between geographic relevance and opacity, colour hue, and saturation, and showed that they all offer a relatively intuitive mapping to relevance values, but that opacity offered the most intuitive mapping. As noted by Garlandini and Fabrikant (2009), the efficiency and effectiveness of these visual variables in communicating has been until recently neglected. The results of this experiment offer a clear indication that variation exists within the effectiveness and efficiency of each visual variable, and that empirical experiments offer a means through which to discover more about this variation. In the more specific context of map semiotics and geographic relevance, the results from Experiment I represent an extension of the work carried out by Swienty et al. (2008b), which looked at the ability of the visual variables to attract attention to relevant map objects.

At the more general level of cartographic theory, the results from the Experiments I can be interpreted from two different standpoints. On the one hand, the visual variables included in the experiment should all be able to intuitively describe an ordinal measure such as relevance rank, and the correlation between perceived rank and actual rank was significantly high for all of these visual variables, as predicted by cartographic theory (Robinson 1995, Bertin 1983). However, it was clear that a small number (2) of the participants, i.e. 10%, were applying a mapping that was the reverse of the one predicted by theory. This implies that the application of cartographic theory to encode relevance cannot be relied upon to communicate relevance in an intuitive manner in all cases, and therefore perhaps some form of map legend is necessary in an actual implementation. The only visual variable that did not suffer from this confusion was opacity, introduced more recently by MacEachren (1992) as an extension to the original list of visual variables from Bertin (1983), which was found to offer the most intuitive mapping for relevance. Opacity is therefore shown as the most applicable to the representation of geographic relevance on map displays. These results agree with the past findings of Olivieri (2012), who tested the intuitiveness of colour value, colour hue and opacity, and found opacity to be the most easily decoded. It is also important to note that from a practical standpoint it has been suggested by Sarjakoski and Nivala (2005) that mobile maps are often employed for outdoor use in dynamic contexts, and that the perception of differences in colour, especially light colours, will become difficult as lighting conditions change. This could therefore result in the differences in opacity values being difficult to perceive in outdoor contexts where sunlight is present. However, if relative differences are stable then this would not affect the encoding of the ordinal relevance rank. To be more certain, further testing would be necessary in order to determine the effects of these external factors. An additional factor introduced by the dynamic context of mobile information seeking will be that relevance will in some circumstances need to be visually encoded in map symbols for other levels of measurement other than ordinal, such as continuous ratio levels of measurement, and will therefore require an empirical analysis incorporating other visual variables aside from those tested in this experiment.

A study by Sutcliffe et al. (2000) investigating the use of visual metaphors in seeking information discovered that even when metaphors are recognised and mapped correctly, they can also change the information seeking process itself, which can then lead to a sub-optimal performance. This therefore resulted in the need to empirically validate these visual metaphors, and such a validation was carried out in Experiment II. Experiment II followed on from Experiment I and applied a similar experimental approach, but instead of defining visual variables according to cartographic theory, a metaphorical approach was taken that made use of basic concepts and structures defined by the theories of cognitive linguistics. However, this approach is based on a different paradigm which aims to support the intuitiveness of the cartographic communication, as described by (Sluter 2009). The results showed that grounding the development of metaphors within cognitive theories can enhance the communicative power of these metaphors for naive users, which was also proposed by both Kuhn (1993) and Slocum et al. (2001). This was especially true for those visual metaphors based on image schema theory. Although some past work has employed image schema to interaction metaphors for map displays (Kuhn 1991) and map legends (Dykes et al. 2010), few studies have used image schema to explicitly influence the design of map symbols and then evaluated these designs. An exception can be found in the work by (Fabrikant and Buttenfield 2001). This therefore lends a degree of originality to the approach taken and represents a further step in the challenge set out by MacEachren and Kraak (2001) to discover appropriate visual metaphors for geo-visualisation. Additionally, it is extending upon work first initiated by Reichenbacher (2005b) in representing Geographic Relevance with visual metaphors. This extension is through the addition of metaphors that can be utilised for representing GR, and through the carrying out of an empirical analysis to discover which of these metaphors can be intuitively linked to geographic relevance. Overall, the more pictorial image schema symbols provided the better results and therefore agrees with the findings of MacEachren and Ganter (1990) that these types of map symbols are more applicable to a less specialised audience, as would be the case for geographic relevance.

Furthermore, the results prove encouraging for the use of image schemas to influence the design process of map symbols, with the FULLEMPTY schema proving to be slightly better than the best visual variable, opacity, from the semiotic approach of Experiment I. One explanation for this is that the FULLEMPTY schema is closely relates to the visual variable size, which past empirical study has determined as an effective communicator of quantity (Garlandini and Fabrikant 2009). The schema of FULLEMPTY also closely matches the concept of relevance as described by Holmqvist and Płuciennik (1996); it is a bounded value; it increases from 0 to a certain level; it is a quality not in and of itself, but of a container object. A second discussion point from this experiment is that the results were much more varied than for Experiment I, with the metaphors designed according to basic domain theory resulting in poor recognition of metaphors and incorrect perceptions of how the metaphors relate to the relevance concept. MacEachren et al. (2012) acknowledge that this recognition problem can occur with symbolisations that utilise metaphors, although they admit that no evidence is available to test out this contention. Looking more closely at the graphs shown in Figure 14 of Chapter 7, it is clear that there is a strong correlation between recognition and accuracy (rank correlation), which perhaps provides some evidence to back this contention up.

Experiment III represents an extension to the first two experiments, and also a validation of the methods described in Chapter 5 which designed representations that enhanced the external cognition of visual representations. The results can be interpreted in relation to research into cognitive science, geovisualisation, map use and research into geographic relevance. From a cognitive science perspective, the experiment shows that participants will not be searching explicitly with the aim of finding a 'relevant' place or event in mind. Rather, they will have some qualities in mind which are derived from goals of the current task context, similar to the psychological variables described by Norman (1986). The ability to recognise how these goals are reached with the visual representation then varies according to the state of that representation, analogous to the physical variables of Norman (1986), with a well designed representation allowing an individual to see clearly how this external medium relates to the goals of a task. In the scenario given, these psychological variables might be '*find an ATM located in my direction of travel'*. The participants then search the map display for ATMs possessing this quality, and when information representing this quality is too abstract (e.g. only opacity visual variables) the participants' interactions suffer from a gap that exists between the psychological and physical variables. The cognitive design process outlined in Chapter 5 however allowed this gap to be bridged through assessment of the information needs of users, tasked with finding objects located in the direction of travel. The results therefore offer support for the contention of Raubal (2009), that the cognitive engineering of interfaces for spatial applications will increase their usefulness and usability.

In the context of geovisualisation, the results support the contention by Fabrikant and Lobben (2009) that empirical validation offers important insights into how efficient and effective geovisualisations can be developed, and that the application of cognitive principles during this design process does add value to the output of that process (Fabrikant et al. 2010). This cognitive process removes the probability of an individual not noticing the spatial patterns and relationships that contribute to the perception of relevance, referred to as a Type II visualisation error by MacEachren (1992). Furthermore, these findings support research which looked into the types of information that must be shown in order for naive users to build knowledge regarding the nature of geographic phenomena. A clear example of this is the work by Lautenschütz (2012), which found that the presentation of contextual information improved the comprehension of movement patterns from geovisualisations.

In the context of map use, the results challenge the methods that judge the complexity of a map only through geometrical analyses that consider the number of objects, and the complexity of their shapes (Li and Huang 2002, Harrie and Stigmar 2009). The map displays that allowed better performances in this experiment contained more objects and would therefore be considered as more complex by these geometric methods. The complexity of the map displays in this experiment would be therefore more similar to what Fairbairn (2006) described as a "*characteristic of the interpretation of the map document*" and what might be more similar to what Castner and Eastman (1985) term 'functional complexity'. This therefore suggests that map complexity would have to be determined by a method that considered not only the state of the visual representation itself but also its relation to the cognition of the user. However, whilst geometrical analysis can be carried out computationally, it is possible that currently functional complexity can only be determined through the application of empirical studies.

For research regarding mobile map use, perhaps the most important contribution of Experiment III is that although the past work has focused mainly on the design of map symbolisations (Carmo et al. 2005, Burigat and Chittaro 2005, Reichenbacher 2005b), more information is required in order for users to relate their goals to the visual representation. From a theoretical standpoint, it would appear that the visual variables are important in directing the bottom up stimulus driven visual processing of the information, but on their own struggle to support the knowledge driven visual attention, both of which play a role during a visual search task (Wolfe 1994). This finding has two impacts. Firstly, as the type of information required is based around the relevance criteria, which is in turn based around the context of the user, it supports the research that suggests contextual adaptation of map interfaces remains an important area of research (Reichenbacher 2005a). Secondly, the findings encourage the use of interface evaluations that make use of eye tracking, as this is a powerful way to measure this stimulus driven bottom up visual attention (Reichenbacher and Swienty 2007, Garlandini and Fabrikant 2009, Heil and Reichenbacher 2009). This experiment shows that analysing eye movements can add insights regarding the cognition of user's interactions, which could further research into the use of mobile interfaces. Without these measurements, the finding that opacity guides the attention to the most relevant locations of a map would not have been apparent, and corroborates findings from past experiments.

8.5 Limitations

8.5.1 Data limitations

The data limitations to this thesis were the lack of open datasets and analyses that can allow the modelling of an actor's spatio-temporal movements and environment. Despite the successes of crowd sourced open data movements, there still remain large gaps in the types of data available and the openness of algorithms which can operate on them. More openness of data and algorithms related to spatio-temporal analyses described in Chapter 4 would mean that the information seeker could be offered more support to choose not just where and when to act, but also how best to travel. Especially lacking is the availability of public transport networks and related algorithms with which to perform these analyses, although the General Transit Feed Specification data being released is beginning to improve this problem. However, without access to this data the development of mobile systems that can understand the spatio-temporal context of a mobile individual and form predictions regarding spatio-temporal accessibility will be limited. Furthermore, in addition to the lack of data to predict movement over space-time, there was also a lack of data to represent the temporal accessibility of the real world places to which these movements would be targeted. This thesis utilised point of interest datasets to represent these places, and the services of these real world places vary over time, e.g. they are open or closed. However, point of interest datasets suffer from preponderance with space, and the temporal data necessary to describe their temporal behaviour is non-existent or incomplete. Without these data, the incorporation of spatio-temporal context into mobile systems will be incomplete and therefore provide inaccurate predictions regarding the activities available to an individual.

8.5.2 Methodological limitations

The conceptual method described in this thesis to design visual representations took a cognitive approach to the design of representations, such as external cognition and metaphor use. However, it is acknowledged that other methods exist with which to develop representations that can both complement the approach described in this thesis or replace it. For example, it would have been possible to follow an empirical method, such as a user-centred design approach, that uses the experiments as a way to develop representations, rather than just as an evaluation tool. How the outcome might differ is difficult to predict, but it is one method that has been highlighted as a valid approach to develop visual representations, as described by MacEachren and Kraak (2001). Aside from the cognitive approach, context was also utilised in the development of the representation of geographic relevance. In defining context, it was necessary to narrow down the rich context of mobile use, with just the main elements suggested by literature, of space, time, and activity being included. Including more or different elements would have been possible resulting in different analyses being necessary. However, determining which contextual elements are relevant and which are not is a subject of ongoing research and at this time difficult to quantify (Huang and Gartner 2011, Keßler 2012). Furthermore, the data limitations also influenced the definition of context. For example, in Chapter 4 the modes of travel available to an individual may also have been interesting to include and would have allowed the inclusion of capability constraints. However, as described above in section 8.5.1, the necessary infrastructure was not available and therefore this element of context was not included.

Also limiting the results of this thesis is one of the fundamental geographical concepts – scale. The representations were developed with the assumption that the searches were being performed at the scale of cities and neighbourhoods, termed by Montello as environmental space (Montello 1993). Although this is most likely the most common use case, situations exist where the direct visible environment, known as vista space, must be searched for relevant objects. In these use cases, the visual representations will need to support the individual's search of the visible area, possibly through systems or services more akin to augmented reality. Although for the mobile use case it is less applicable, it is also imaginable that larger scale spaces than environmental space will need to be sought through for relevant places, and which would again require different approaches.

The cognitive model, CogTool, used as a means of evaluation in Chapter 5 possessed numerous limitations when faced with the complexity of a map interface. The main limitation is that it models only the cognition of an individual resulting from physically manipulating the interface, such as pushing buttons or typing text. Maps also require a significant amount of visual attention, a type of cognition not modelled by CogTool, which would require a more sophisticated cognitive architecture to be applied. Models that possess this functionality do exist, such as ACT-R or Soar (Anderson et al. 1997), but require a substantial amount of expertise to properly model the tasks that can be carried out with a map interface. However, this would enable the visual representations to be more rigorously tested and would therefore provide a more thorough assessment of the designs presented in Chapter 5.

The experiment phase in this thesis included limitations regarding the participants and the type of experimental setting chosen. The participants for these experiments were contacted via academic mailing lists, or were recruited on the university campus. This sampling of participants may hence be biased in terms of education levels and past experience with digital maps and geo-visualisations for Experiment I. The generalisability of the results would therefore need to be investigated further with user groups containing a greater variance in background, representative of the typical user types that would seek information from representations of geographic relevance. In addition to limitations of participants, the experimental settings were also limited as they did not include field experiments, which would provide greater ecological validity to the results. As this research represents a first step in the representation of geographic relevance, the approach taken was necessary, and can be thought of as the first step in the process of evaluation that could lead to field experiments. However, as geographic relevance is a concept tightly bound with mobility field, experiments are likely to be an important step in the continuing work to evaluate its usefulness of geographic relevance to mobile information seekers.

Chapter 9 Conclusion

9.1 Summary

The aim of this thesis was to develop visual representations of geographic relevance that improve decision making and support activities of mobile users. This was carried out by first developing a framework that incorporated context and cognition into the process of designing visual representations of geographic relevance. A workflow was then developed to guide the exploration of this framework, which first addressed how to filter the relevance data using the contextual analyses of spatio-temporal activity for a mobile information seeker. Following this, the application of the theory of external cognition allowed an enrichment of the remaining data, and created visual representations that were able to clearly communicate the relevance of map objects. A key finding of this phase was that cognition of an individual can be offloaded onto a visual representation of relevance. The next phase was the description of a categorisation methodology for each relevance criterion of geographic relevance, the use of which was demonstrated through the development of a faceted search tool. Additionally, the communicational and interactional aspects of geographic relevance were looked at in more detail through the analysis and application of linguistic, visual, and interactional metaphors. Lastly, the evaluations looked into the ability of visual variables and metaphors to provide intuitive mappings for the geographic relevance of map objects. The results showed that opacity and the full-empty metaphor provided the most intuitive mappings to geographic relevance. Also explored by the evaluation was the effect of the explicitness of the visual representation to the intuitiveness of the spatio-temporal proximity relevance criterion. The results from this experiment showed that increasing the explicitness also increased the intuitive perception of geographic relevance, but that the utility of adding information to a visualisation eventually diminishes.

9.2 Scientific Contributions

The contributions of this thesis lie in three main areas of research. The first contribution is the demonstration of the value of spatio-temporal context analyses for mobile information seekers. Furthermore, there is an importance in distinguishing between information needs relating to the planning of spatial activities, and the acting out of these plans in the process of representing geographic relevance for mobile information seekers. This finding has an impact upon the fields of time geography and context aware computing.

A second contribution lies in the introduction and evaluation of cognitive theories such as image schemas and external cognition to the development of mobile map representations. These findings impact upon the research into the creation of methods that can be used to develop visual representations of spatial phenomena, as external cognition is a general theory that can be applied to numerous other areas that require the inclusion of cognitive principles to the development of geo-visualisation. The application of cognitive structures to design symbologies can also be applied to the communication of relevance in a more general setting but also most likely to the communication of other phenomena that share a similar structure.

Finally, a more specific contribution is to the recent field of geographic relevance, as this thesis represents a step further in the development of this recently introduced concept. Perhaps the most significant findings come from the results of the experiments described in Chapter 7. For example, evidence was found that metaphors are able to intuitively communicate geographic relevance within map symbols. Furthermore, whilst past research into the visual representation of geographic relevance has focused mostly on map symbologies, the third experiment shows evidence that more information is required besides the symbologies in order for the relevance of map objects to be quickly and correctly understood. Lastly, an important contribution is to recognise that these results lead to several possible future research directions, discussed in the section below.

9.3 Future Work

As stated above, this thesis offers the opportunity for several new research directions in the field of geographic relevance and location based services. Possible future work represents extensions to the findings of this thesis, or other directions that could be explored that relate to the presented work.

Planning/Acting – The planning and acting elements of a mobile information seeker were explored in this thesis, but only during the spatio-temporal filtering in Chapter 4. However, it could be applied to many other areas covered in this thesis. A process that would benefit from this contextual division is the development of interaction tools, as it is very possible that the information seeker would need to solve differing tasks during the information seeking process for acting and planning, and also have different information needs. Furthermore, as highlighted in the discussion section, planning suggests that geographic relevance will also be applicable to stationary users at desktop computers. The context of use differs greatly from the mobile use case, and thus new methods to design geo-visualisations that help the building of these plans will be a necessary and important step in the overall work of representing geographic relevance.

Space-Time - The work in Chapter 4 covered some basic amendments to time schedules, but the full list of possible alterations was not covered in any detail. To fully realise the ideas presented in this work, it would be necessary to develop an algorithm that can robustly deal with all of these amendments and provide the optimal solution given the new set of constraints that must be incorporated into the model. Ideally, these algorithms would also be able to use real-time information, such as the lateness of trains or worsening of traffic conditions, to automatically adapt to the unfolding spatio-temporal events and alterations to constraints. This therefore requires not only new methods but also new sources of streaming data, both of which do not currently exist. Following on from this, it is suggested that a more open and collaborative approach to the development of spatio-temporal algorithms based around non-proprietary software would benefit researchers involved with time geographical analyses.

Decision Making - Although a great deal of research into decision making behaviour has been carried out in the past, no empirical studies have been carried out into the decision making behaviours of LBS users. Instead the focus has tended to the development of decision making tools, but basic questions still remain regarding the decision strategies that mobile users employ during their information seeking behaviours. Only through the elucidation of these strategies can the more basic questions be answered, such as how many alternatives should be presented to the user, in what contexts should criteria be weighted and combined automatically, and when the combination and weighting of the criteria should be carried out through interactive tools using Multi Criteria Decision tools.

Representation – The representation of geographic relevance in this thesis concentrated on point objects, but it is foreseeable that the representation of relevance for higher dimensional objects (lines, regions) is also necessary. One clear difference with these objects is that the relevance may vary along or within these objects, e.g. the steeply inclined sections of a hiking path might become more relevant to a hiker. It would therefore be of interest to investigate how this spatial variance should then be represented visually in a comprehensible way. Furthermore, only five relevance criteria were explored within chapter 5 but many others remain, and which could be explored as an extension to this work. Some of these criteria that remain to be represented are difficult to quantify, such as Place or Hierarchy, and therefore representing them may also be more complicated and require a different approach than the one taken. Furthermore, a valuable piece of research would be to find how to derive the elements of the representation vital to the perception of relevance through analysis of contextual information. This analysis would attempt to discover which relevance criteria are applicable in which contexts and then create visual representations that contain information elements (overlays, user locations) adapted to the given information seeking context. Another possible extension to the development of representations of geographic relevance could look into the incorporation of geographic relevance into systems other than just map displays. These could range from visual highlighting of relevant objects within augmented reality displays, the communication of relevance with list views as well as other forms context of communication besides visual.

Evaluation - Evaluations in this thesis were all desktop based, and it is acknowledged that perhaps future evaluations should move into the field in order to give the results more ecological validity. Certainly the improvement in the sophistication of mobile eye tracking makes this a worthwhile pursuit, as it will allow these evaluations to become more comprehensive and measure not only performance, but also the attention of the participants whilst they are in a realistic setting. However, a significant amount of work will first be necessary to develop a system that can allow these field evaluations to be carried out, in both the representation of geographic relevance, but also within its assessment.

References

Abdalla, A. and Frank, A. U., 2011. Personal geographic Information Management. *CeMob 2011 : Workshop on Cognitive Engineering for Mobile GIS 2011*, Sep 12, 2011, Belfast, Maine, USA.

Achatschitz, C., 2005. Identifying the necessary information for a spatial decision: Camping for Beginners. *CORP 2005*, February, Vienna University of Technology.

Akcay, O. and Altan, O., 2007. Ontology for context-aware visualization of spatial data in mobile devices. *Visualization and Exploration of Geospatial Data*, June 27 - 29, Stuttgart, Germany.

Amin, A., Townsend, S., van Ossenbruggen, J. and Hardman, L., 2009. Fancy a Drink in Canary Wharf?: A User Study on Location-Based Mobile Search. *In:* Gross, T., Gulliksen, J., Kotzé, P., Oestreicher, L., Palanque, P., Prates, R. and Winckler, M. eds.: Springer Berlin / Heidelberg, 736-749.

Anderson, J. R., Matessa, M. and Lebiere, C. 1997. ACT-R: A theory of higher level cognition and its relation to visual attention. *Human-Computer Interaction,* 12(4), 439-462.

Barkowsky, T., 2002. *Mental representation and processing of geographic knowledge: a computational approach.* Springer-Verlag New York Inc.

Barkowsky, T. and Freksa, C., 1997. Cognitive requirements on making and interpreting maps. *In:* Hirtle, S. and Frank, A. eds. *Spatial information theory: A theoretical basis for GIS.* Berlin Heidelberg Springer, 347 - 361.

Battersby, S. E., 2008. User-centered design for digital map navigation tools. *Proceedings of AutoCarto2008. The 17th International Research Symposium on Computer-based Cartography*, September 8-11, 2008, Shepherdstown, West Virginia, USA.

Baudisch, P. and Rosenholtz, R., 2003. Halo: a technique for visualizing off-screen objects. *CHI '03 Proceedings of the SIGCHI conference on Human factors in computing systems*, April 5-10, 2003, Fort Lauderdale, Florida, 481-488.

Bäumer, B., Panov, I. and Raubal, M., 2007. Decision improvement through multi-Criteria strategies in mobile location-based services. *Geospatial Crossroads @ GI_Forum: Proceedings of the First Geoinformatics Forum Salzburg*, Salzburg, Austria, 17-25.

Baus, J., Cheverst, K. and Kray, C., 2003. A survey of map-based mobile guides. *In:* Zipf, A., Meng, L. and Reichenbacher, T. eds. *Map-based mobile services-Theories, Methods, and Implementations.* Berlin: Springer-Verlag, 197–216.

Bearne, M., Jones, S. and Sapsford-Francis, J., 1994. Towards usability guidelines for multimedia systems. *Proceedings of the second ACM International Conference on Multimedia*, 15th - 20th October, San Francisco, US, 105-110.

Bellotti, V. and Edwards, K. 2001. Intelligibility and accountability: human considerations in context-aware systems. *Hum.-Comput. Interact.,* 16(2), 193-212.

Bereuter, P., Venkateswaran, R. and Weibel, R., 2009. The Use of Filters for Adaptive Mobile Mapping Scenarios. *Proceedings of AGILE 2009 Workshop on Adaptation in Spatial Communication*, June 2-5, Bremen, Germany, 39-44.

Bereuter, P., Weibel, R. and Burghardt, D., 2012. Content zooming and exploration for mobile maps. *Proceedings of the AGILE 2012 International Conference of Geographic Information Science*, 25 - 27 April, Avignon, France, 74–80.

Bertin, J. 1983. Semiology of Graphics: diagrams, networks, maps. *Madison: University of Wisconsin Press.(Original work published 1973)*.

Bian, L. 2007. Object-Oriented Representation of Environmental Phenomena: Is Everything Best Represented as an Object? *Annals of the Association of American Geographers,* 97(2), 267-281.

Brimicombe, A. and Li, Y. 2006. Mobile Space-Time Envelopes for Location-Based Services. *Transactions in GIS,* 10(1), 5-23.

Bunch, R. L. and Lloyd, R. E. 2006. The Cognitive Load of Geographic Information. *The Professional Geographer,* 58(2), 209-220.

Burigat, S. and Chittaro, L., 2005. Visualizing the results of interactive queries for geographic data on mobile devices. *Proceedings of the 13th annual ACM international workshop on Geographic information systems*, October 31- November 5, Bremen, Germany, 277-284.

Burigat, S. and Chittaro, L., 2007. Geographical Data Visualization on Mobile Devices for User's Navigation and Decision Support Activities. *Spatial Data on the Web–Modelling and Management.* Berlin: Springer, 261–284.

Cai, G. and Xue, Y., 2006. Activity-oriented context-aware adaptation assisting mobile geo-spatial activities. *Proceedings of the 11th international conference on Intelligent user interfaces*, January 29 - February 1, Sydney, Australia.

Card, S. K., Moran, T. P. and Newell, A., 1983. *The psychology of human-computer interaction.* Erlbaum, Hillsdale, NJ: CRC.

Carlier, I. V. E., Lamberts, R. D. and Gersons, B. P. R. 2000. The dimensionality of trauma: a multidimensional scaling comparison of police officers with and without posttraumatic stress disorder. *Psychiatry Research,* 97(1), 29-39.

Carmo, M., Afonso, A., Pombinho de Matos, P. and Vaz, A. 2008. MoViSys–a visualization system for geo-referenced information on mobile devices. *Visual Information Systems. Web-Based Visual Information Search and Management*, 167-178.

Carmo, M. B., Afonso, A. P. and Matos, P. P., 2007. Visualization of geographic query results for small screen devices. *GIR '07: Proceedings of the 4th ACM workshop on Geographical information retrieval*, November 6, Lisbon, Portugal, 167-168.

Carmo, M. B., Freitas, S., Afonso, A. P. and Cláudio, A. P., 2005. Filtering mechanisms for the visualization of geo-referenced information. *Proceedings of the 2005 Workshop On Geographic Information Retrieval (GIR 2005)*, November 4, Bremen, Germany, 1-4.

Carroll, J. M. and Thomas, J. C. 1982. Metaphor and the cognitive representation of computing systems. *IEEE Transactions on systems, man and cybernetics,* 12(2), 107-116.

Cartwright, W., Crampton, J., Gartner, G., Miller, S., Mitchell, K., Siekierska, E. and Wood, J. 2001. Geospatial information visualization user interface issues. *Cartography and Geographic Information Science,* 28(1), 45-60.

Castner, H. W. and Eastman, R. J. 1984. Eye-Movement Parameters and Perceived Map Complexity I. *Cartography and Geographic Information Science,* 11(2), 107-117.

Castner, H. W. and Eastman, R. J. 1985. Eye-Movement Parameters and Perceived Map Complexity II. *Cartography and Geographic Information Science,* 12(1), 29-40.

Chandrasekaran, B., 2006. What makes a bunch of marks a diagrammatic representation, and another bunch a sentential representation. *Proceedings of the AAAI Spring Symposium, Reasoning with Mental and External Diagrams: Computational Modeling and Spatial Assistance*, March 21-23, Palo Alto, CA.

Chen, C., Gärling, T. and Kitamura, R. 2004. Activity rescheduling: reasoned or habitual? *Transportation Research Part F: Traffic Psychology and Behaviour,* 7(6), 351-371.

Chernoff, H. 1973. The use of faces to represent points in k-dimensional space graphically. *Journal of the American Statistical Association,* 68(342), 361-368.

Cheung, Y. K., Li, Z. and Chen, W. 2009. Integration of Cognition-based Content Zooming and Progressive Visualization for Mobile-based Navigation. *The Cartographic Journal,* 46(3), 268-272.

Choo, C. W., Detlor, B. and Turnbull, D. 2000. Information seeking on the Web. *First Monday,* 5(2-7).

Church, K., Smyth, B., Bradley, K. and Cotter, P., 2008. A large scale study of European mobile search behaviour. *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*, September 2-5, Amsterdam, the Netherlands, 13-22.

Clausner, T. C. and Croft, W. 1999. Domains and image schemas. *Cognitive linguistics,* 10, 1-32.

Cockburn, A., Karlson, A. and Bederson, B. 2009. A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. *ACM Computing Surveys,* 41(1).

Coppola, P., Della Meal, V., Di Gaspero, L. and Mizzaro, S., 2004. The concept of relevance in mobile and ubiquitous information access. *Mobile and Ubiquitous Information Access*, February 19th, 3 - 6.

Couclelis, H., 1993. People Manipulate Objects (but Cultivate Fields): Beyond the Raster-Vector Debate in GIS. *From Space to Territory : Theories and methods of spatio-temporal reasoning in geographic space*, Pisa, Italy, 65- 77.

Couclelis, H., 1996. Towards an Operational Typology of Geographic Entities with Ill-defined Boundaries. *In:* Burrough, P. A., Frank, A. U., Bristol, P., Masser, I. and Salgé, F. eds. *Geographic objects with indeterminate boundaries.* London, UK: Taylor & Francis, 45 - 55.

Couclelis, H. 1998. Worlds of Information: The Geographic Metaphor in the Visualization of Complex Information. *Cartography and Geographic Information Science*, 25(4), 209-220.

Couclelis, H. 2003. The Certainty of Uncertainty: GIS and the Limits of Geographic Knowledge. *Transactions in GIS,* 7(2), 165-175.

Cova, T. J. and Goodchild, M. F. 2002. Extending geographical representation to include fields of spatial objects. *International Journal of Geographical Information Science,* 16(6), 509-532.

Crease, P., 2012. Time Geography in Support of Mobile Activity Planning. *GISRUK 2012*, 13 - 15 April, Lancaster, UK, 213 - 219.

Crease, P. and Reichenbacher, T., 2011. Designing Usable Cartographic Representations for Mobile Information Seeking. *Proceedings of the International Cartographic Conference 2011*, July 3 - 8, 2011, Paris, France.

Crease, P. and Reichenbacher, T. 2013. Linking time geography and activity theory to support the activities of mobile information seekers. *Transactions in GIS,* 17(4), 507-525.

Cromley, R. and Mrozinski, R. 1999. The Classification of Ordinal Data for Choropleth Mapping. *The Cartographic Journal,* 36(2), 101-109.

Crossland, M. D., Wynne, B. E. and Perkins, W. C. 1995. Spatial decision support systems: An overview of technology and a test of efficacy. *Decision Support Systems,* 14(3), 219-235.

De Sabbata, S., 2010. Criteria of Geographic Relevance. *Proceedings of the 6th International Conference on Geographic Information Science*, September 15 - 17, 2010, Zürich, Switzerland.

De Sabbata, S., 2013. *Assessing Geographic Relevance for Mobile Information Services.* (PhD Thesis). University of Zurich.

De Sabbata, S. and Reichenbacher, T., 2010. A probabilistic model of geographic relevance. *Proceedings of the 6th Workshop on Geographic Information Retrieval*, February 18-19, Zurich, Switzerland.

De Sabbata, S. and Reichenbacher, T. 2012. Criteria of geographic relevance: an experimental study. *International Journal of Geographical Information Science,* 26(8), 1-26.

Densham, P. 1991. Spatial decision support systems. *Geographical information systems: Principles and applications,* 1, 403-412.

Dervin, B., 1983. An overview of sense-making research: Concepts, methods, and results to date. *International Communications Association Annual Meeting*, Dallas, Texas.

Dey, A. K. 2001. Understanding and Using Context. *Personal Ubiquitous Comput.,* 5(1), 4--7.

Dey, A. K. and Abowd, G. D., 2000. Towards a Better Understanding of Context and Context-Awareness. *Proceedings of the What, Who, Where, When, and How of Context-Awareness Workshop*, February 14, Atlanta, 304-307.

Dijst, M. and Vidakovic, V. 2000. Travel time ratio: the key factor of spatial reach. *Transportation,* 27(2), 179-199.

Dillemuth, J. 2005. Map Design Evaluation for Mobile Display. *Cartography and Geographic Information Science,* 32(4), 285-301.

Dillemuth, J. A. 2009. Navigation Tasks with Small-Display Maps: The Sum of the Parts Does Not Equal the Whole. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 44(3), 187-200.

Dix, A., Rodden, T., Davies, N., Trevor, J., Friday, A. and Palfreyman, K. 2000. Exploiting space and location as a design framework for interactive mobile systems. *ACM Trans. Comput.-Hum. Interact.*, 7(3), 285--321.

Dransch, D., 2005. Activity and Context — A Conceptual Framework for Mobile Geoservices. *In:* Meng, L., Zipf, A. and Reichenbacher, T. eds. *Map-based Mobile Services.* 31-42.

Drew, M. 1978. Planning and acting. *Cognitive science,* 2(2), 71-109.

Dunlop, M. D., Elsey, B. and Masters, M. M., 2007. Dynamic visualisation of ski data: a context aware mobile piste map. *Proceedings of the 9th international conference on Human computer interaction with mobile devices and services*, September 11 - 14, Singapore, 375-378.

Dykes, J., Wood, J. and Slingsby, A. 2010. Rethinking map legends with visualization. *Visualization and Computer Graphics, IEEE Transactions on,* 16(6), 890-899.

Edwardes, A. J., 2007. *Re-placing Location: Geographic Perspectives in Location Based Services.* (PhD Thesis). University of Zürich.

Edwardes, A. J., Burghardt, D. and Weibel, R., 2005. Portrayal and Generalisation of Point Maps for Mobile Information Services. *In:* Meng, L., Zipf, A. and Reichenbacher, T. eds. *Map-based Mobile Services.* Springer Verlag., 11 - 28.

Edwardes, J. A., 2009. Geographical perspectives on location for location based services. *Proceedings of the 2nd International Workshop on Location and the Web*, April 4, Boston, Massachusetts.

Egenhofer, M. J. and Franzosa, R. D. 1991. Point-set topological spatial relations. *International journal of geographical information systems,* 5(2), 161-174.

Elzakker, C. P. J. M. v., Oosterom, P. J. M. v. and Delikostidis, I., 2007. Testing the Usability of Well-scaled Mobile Maps for Consumers. *In Proceedings of the XXIII International Cartographic Conference Congress*, 4–10 August, Moscow, Russia.

Erickson, T. D., 1990. Working with interface metaphors. *Human-Computer Interaction.* San Francisco, CA: Morgan Kaufmann Publishers, 147-151

Espeter, M. and Raubal, M. 2009. Location-based decision support for user groups. *Journal of Location Based Services*, 3(3), 165-187.

Evans, V. and Green, M. C., 2006. *Cognitive linguistics: An introduction.* Edinburgh university press.

Fabrikant, S. I. and Buttenfield, B. P. 2001. Formalizing Semantic Spaces for Information Access. *Annals of the Association of American Geographers*, 91(2), 263-280.

Fabrikant, S. I., Hespanha, S. R. and Hegarty, M. 2010. Cognitively inspired and perceptually salient graphic displays for efficient spatial inference making. *Annals of the Association of American Geographers,* 100(1), 13-29.

Fabrikant, S. I. and Lobben, A. 2009. Introduction: Cognitive Issues in geographic information visualization. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 44(3), 139-143.

Fadel, J. 2009. Affordance based design: a relational theory for design. *Research in Engineering Design*, 20(1).

Fairbairn, D. 2006. Measuring Map Complexity. *The Cartographic Journal*, 43(3), 224-238.

Fairbairn, D., Gennady, A., Andrienkon, N., Buziek, G. and Dykes, J. 2001. Representation and its relationship with cartographic visualization: a research agenda. *Cartography and Geographic Information Science,* 28(1), 1-28.

Fairthorne, R. A. 2005. Empirical hyperbolic distributions (Bradford-Zipf-Mandelbrot) for bibliometric description and prediction. *Journal of Documentation*, 61(2), 171-193.

Fischer, G., 1983. Shared knowledge in cooperative problem-solving systems – integrating adaptive and adaptable components. *In:* Schneider-Hufschmidt, M., Kühme, T. and Malinowski, U. eds. *Adaptive user interfaces: Principles and practice.* Amsterdam: North-Holland, 49–68.

Frank, A. U., 2000. Spatial Communication with Maps: Defining the Correctness of Maps Using a Multi-Agent Simulation. *In:* Freksa, C., Brauer, W., Habel, C. and Wender, K. eds. *Spatial Cognition II - Integrating Abstract Theories, Empirical Studies, Formal Methods, and Practical Applications.* Springer-Verlag, 80-99.

Franklin, N. and Tversky, B. 1990. Searching imagined environments. *Journal of Experimental Psychology: General; Journal of Experimental Psychology: General,* 119(1), 63.

Freksa, C., Klippel, A. and Winter, S., 2005. A Cognitive Perspective on Spatial Context. *Dagstuhl Seminar Proceedings - Spatial Cognition: Specialization and Integration*, 4 December - 9 December, Internationales Begegnungs- und Forschungszentrum fur Informatik (IBFI), Schloss Dagstuhl, Germany.

Frontiera, P. L., 2008. Flamenco+ Geo: Extending a hierarchical faceted metadata search interface with geographic capabilities. *Proceedings of the 2nd international workshop on Geographic Information Retrieval*, October 26 - 30, Napa Valley, CA, USA, 55-56.

Galant, K. 2006. Data Classification from Cartographic Point of View. *Electronic Journal of Polish Agricultural University*, 9(4).

Galton, A. 2004. Fields and objects in space, time, and space-time. *Spatial Cognition & Computation*, 4(1), 39-68.

Garlandini, S. and Fabrikant, S., 2009. Evaluating the effectiveness and efficiency of visual variables for geographic information visualization. *9th Conference in Spatial Information Theory* September 21 - 25, Wrac'h, France, 195-211.

Gibson, J., 1977. The concept of affordances. *In:* Shaw, R. E. and Bransford, J. eds. *Perceiving, acting, and knowing.* LEA, Hillsdale: Lawrence Erlbaum, 67-82.

Golledge, R. G., Marsh, M. and Battersby, S. 2008. Matching Geospatial Concepts with Geographic Educational Needs. *Geographical Research,* 46(1), 85-98.

Golledge, R. G. and Stimson, R. J., 1997. *Spatial behavior: A geographic perspective.* The Guilford Press.

Gong, J. and Tarasewich, P., 2004. Guidelines for handheld mobile device interface design. *Proceedings of the Decision Sciences Institute Annual Meeting*, Nov. 20 - 23, 2004, Boston, Massachusetts, 3751-3756.

Goodchild, M. F., Juan, M. and Cova, T. J. 2007. Towards a general theory of geographic representation in GIS. *International Journal of Geographic Information Science,* 23(1), 239 - 260.

Grady, J. E., 2005. Image schemas and perception: Refining a definition. *In:* Hampe, B. (ed.) *From perception to meaning: image schemas in cognitive linguistics.* De Gruyter Mouton, 35 - 55.

Greenberg, S. 2001. Context as a dynamic construct. *Human-Computer Interaction,* 16(2), 257-268.

Habel, C., 2003. Representational Commitment in Maps. *In:* Duckham, M., Goodchild, M. F. and Worboys, M. eds. *Foundations of geographic information science.* CRC Press, 69-95.

Hagenauer, J. and Zipf, A., 2010. Generating Focus Maps Using Open Standards. *GIScience 2010*, 14 - 17 September, Zürich, Switzerland.

Hägerstrand, T. 1970. What about people in regional science? *Papers in Regional Science,* 24(1), 6-21.

Hamilton, A. 2000. Metaphor in theory and practice: the influence of metaphors on expectations. *ACM Journal of Computer Documentation (JCD),* 24(4), 237-253.

Hampe, M. and Paelke, V., 2005. Adaptive maps for mobile applications. *Workshop 'Mobile Maps 2005' at MobileHCI*, 19. September Salzburg Austria.

Harrie, L. and Stigmar, H., 2009. Methods to Measure Map Readability. *Dagstuhl Seminar 09161*, April 13 – 17, Internationales Begegnungs- und Forschungszentrum fur Informatik (IBFI), Schloss Dagstuhl, Germany.

Harrower, M. and Sheesley, B. 2005. Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS,* 9(2), 77-89.

Häubl, G. and Trifts, V. 2000. Consumer Decision Making in Online Shopping Environments: The Effects of Interactive Decision Aids. *Marketing Science,* 19(1), 4-21.

Hawksey, M., 2012. *Twitter Archiving Google Spreadsheet TAGS v3* [online]. Available from: http://mashe.hawksey.info/2012/01/twitter-archive-tagsv3/ [Accessed 01-Jan-2012.

Hearst, M., 2008. Design recommendations for hierarchical faceted search interfaces. *Proceedings of SIGIR 2006 - Workshop on Faceted Search*, 20-24 July, Singapore, 26–30.

Hearst, M., Elliott, A., English, J., Sinha, R., Swearingen, K. and Yee, K. P. 2002. Finding the flow in web site search. *Communications of the ACM,* 45(9), 42-49.

Hegarty, M., 2004. Diagrams in the mind and in the world: Relations between internal and external visualizations. *In:* Blackwell, A., Marott, K. and Shimojima, A. eds. *Diagrammatic Representation and inference. Lecture Notes in Artificial Intelligence.* Berlin Springer, 1 - 13.

Heil, B. and Reichenbacher, T., 2009. Geographic Information Interfaces and the use of guidelines to obtain usability. *Proceedings of the 24th International Cartographic Conference (CD-ROM)*, 15-21 November, Santiago, Chile.

Hermann, F., Bieber, G. and Duesterhoeft, A., 2003. Egocentric Maps on Mobile Devices. *International Workshop on Mobile Computing*, Rostock, 32-37.

Hernández, D., Clementini, E. and Di Felice, P., 1995. Qualitative distances. *In:* Frank, A. and Kuhn, W. eds. *Spatial Information Theory A Theoretical Basis for GIS.* Springer Berlin / Heidelberg, 45-57.

Hintzman, D. L., O'Dell, C. S. and Arndt, D. R. 1981. Orientation in cognitive maps. *Cognitive Psychology,* 13(2), 149-206.

Hobona, G., James, P. and Fairbairn, D. 2006. Multidimensional visualisation of degrees of relevance of geographic data. *International Journal of Geographical Information Science,* 20(5), 469-490.

Höllerer, T. and Feiner, S., eds., 2004. *Mobile augmented reality.* London, UK: Taylor and Francis.

Holmqvist, K. and Płuciennik, J. 1996. Conceptualised deviations from expected normality: A Semantic comparison between lexical items ending in-ful and-less. *Nordic journal of linguistics,* 19(01), 3-33.

Hornsby, K. 2001. Temporal zooming. *Transactions in GIS,* 5(3), 255-272.

Huang, H. and Gartner, G., 2008. Using Activity Theory to Identify Relevant Context Parameters. *Location Based Services and Telecartography II.* Springer Berlin Heidelberg, 35-47.

Huang, H. and Gartner, G., 2011. Incorporating context-aware collaborative filtering into Location Based Services. *25th International Cartographic Conference ICC,* 3 - 8 July, 2011, Paris, France.

Huang, H., Schmidt, M. and Gartner, G. 2012. Spatial Knowledge Acquisition with Mobile Maps, Augmented Reality and Voice in the Context of GPS-based Pedestrian Navigation: Results from a Field Test. *Cartography and Geographic Information Science,* 39(2), 107-116.

Huiskes, M. J. and Lew, M. S., 2008. The MIR flickr retrieval evaluation. *Proceedings of the 1st ACM international conference on Multimedia information retrieval*, October 26 - 31, Vancouver, Canada, 39-43.

Hurtienne, J. and Blessing, L., 2007. Design for Intuitive Use-Testing image schema theory for user interface design. *Proceedings of the 16th International Conference on Engineering Design*, 28 - 31 August, Paris, France, 1-12.

Hutchins, E., 2000. Distributed cognition. *In:* Smelser, N. J. and Baltes, P. B. eds. *International Enciclopedia of the Social and Behavioral Sciences.* Kidlington Oxford: Elsevier Sciences Ltd.

Jackson, J. P., 1990. *Visualization of metaphors for interaction with geographic information systems.* (MSc Thesis). University of Maine.

Jansen, B. J. and Spink, A., 2003. An analysis of web documents retrieved and viewed. *International Conference on Internet Computing*, 23-26 June, Las Vegas, Nevada, 65-69.

Jiang, B. and Yao, X. 2006. Location-based services and GIS in perspective. *Computers, Environment and Urban Systems,* 30(6), 712-725.

John, B. and Suzuki, S., 2009. Toward Cognitive Modeling for Predicting Usability. *Proceedings of HCI International*, 19-24 July, San Diego, CA, 267-276.

John, B. E. and Jastrzembski, T. S., 2010. Exploration of costs and benefits of predictive human performance modeling for design. *Proceedings of the 10th International Conference on Cognitive Modeling*, August 6-8,, Philadelphia, PA, 115-120.

John, B. E., Prevas, K., Salvucci, D. D. and Koedinger, K., 2004. Predictive Human Performance Modeling Made Easy. *Human Factors in Computing Systems: CHI 2004 Conference Proceedings*, April 24-29, 2004, Vienna, Austria.

Johnson, E. J. and Payne, J. W. 1985. Effort and Accuracy in Choice. *Management Science,* 31(4), 395-414.

Johnson, M., 1987. *The body in the mind: The bodily basis of meaning, imagination, and reason.* University of Chicago Press.

Jones, C. B. and Purves, R. S. 2008. Geographical information retrieval. *International Journal of Geographical Information Science*, 22(3), 219-228.

Jones, M., Marsden, G., Mohd-Nasir, N., Boone, K. and Buchanan, G. 1999. Improving Web interaction on small displays. *Computer Networks,* 31(11–16), 1129-1137.

Kaptelinin, V. and Nardi, B. A., 2006. Activity Theory in a Nutshell. *Acting with Technology: Activity Theory and Interaction Design.* Cambridge, MA: MIT Press, 29-72.

Kaptelinin, V., Nardi, B. A. and Macaulay, C. 1999. Methods & tools: The activity checklist: a tool for representing the "space" of context. *interactions,* 6(4), 27-39.

Karlson, A. K., Robertson, G. G., Robbins, D. C., Czerwinski, M. P. and Smith, G. R., 2006. FaThumb: a facet-based interface for mobile search. *Proceedings of the SIGCHI conference on Human Factors in computing systems*, April 22-27, Montréal, Canada, 711-720.

Keevil, B., 1998. Measuring the usability index of your Web site. *Proceedings of the 16th annual international conference on Computer documentation*, September 24 - 26, 1998, Quebec, Canada, 271-277.

Keller, P. and Keller, M., 1993. *Visual cues : practical data visualization* Los Alamitos, CA: IEEE Computer Society Press; IEEE Press

Keßler, C. 2012. What is the Difference? A Cognitive Dissimilarity Measure for Information Retrieval Result Sets. *Knowledge and Information Systems,* 30(2), 319–340.

Kiefer, P., Raubal, M. and Schlieder, C., 2010. Time geography inverted: recognizing intentions in space and time. *Proceedings of the 18th SIGSPATIAL International Conference on Advances in Geographic Information Systems*, November 03 - 05, San Jose, California, 510-513.

Kiefer, P. and Schlieder, C., 2007. Exploring context-sensitivity in spatial intention recognition. *ER Workshops 2007*, November 5-9, Auckland, New Zealand, 338-347.

Kiefer, P., Straub, F. and Raubal, M., 2012. Location-aware mobile eye tracking for the explanation of wayfinding behavior. *Proceedings of the AGILE'2012 International Conference on Geographic Information Science*, 13 - 17 August, Avignon, France.

Kitchin, R. M. 1994. Cognitive maps: What are they and why study them? *Journal of Environmental Psychology,* 14(1), 1-19.

Knoblauch, R. L., Pietrucha, M. T. and Nitzburg, M. 1996. Field studies of pedestrian walking speed and start-up time. *Transportation Research Record: Journal of the Transportation Research Board,* 1538(-1), 27-38.

Kohavi, R. and John, G. H. 1997. Wrappers for feature subset selection. *Artificial Intelligence,* 97(1-2), 273-324.

Kolány, A. 1969. Cartographic Information - a Fundamental Concept and Term in Modern Cartography. *Cartographic Journal, The,* 6(1), 47-49.

Kray, C., Elting, C., Laakso, K. and Coors, V., 2003. Presenting route instructions on mobile devices. *Proceedings of the 8th international conference on Intelligent user interfaces*, January 12 - 15, Miami, Florida, USA, 117-124.

Krüger, A., Baus, J., Heckmann, D., Kruppa, M. and Wasinger, R., 2007. Adaptive Mobile Guides. *In:* Brusilovsky, P., Kobsa, A. and Nejdl, W. eds. *The adaptive web.* Springer Berlin Heidelberg, 521-549.

Kuhn, W., 1991. Are displays maps or views? *AutoCarto 10*, March 25-28, Baltimore, MD, 271-284.

Kuhn, W., 1993. Metaphors create theories for users. *In:* Frank, A. U. and Campari, I. eds. *Spatial Information Theory: Theoretical Basis for GIS.* Heidelberg-Berlin: Springer-Verlag, 366-366.

Kwan, M.-P. 2008. From oral histories to visual narratives: re-presenting the post-September 11 experiences of the Muslim women in the USA. *Social & Cultural Geography,* 9(6), 653-669.

Kwan, M. and Hong, X. 1998. Network-based constraints-oriented choice set formation using GIS. *Geographical Systems,* 5, 139-162.

Kwan, M. P. 2000. Gender differences in space-time constraints. *Area,* 32(2), 145-156.

Lakoff, G. 1973. Hedges: A study in meaning criteria and the logic of fuzzy concepts. *Journal of philosophical logic,* 2(4), 458-508.

Lakoff, G. 1990. The invariance hypothesis: Is abstract reason based on image-schemas. *Cognitive linguistics,* 1(1), 39-74.

Lakoff, G. and Johnson, M., 1980. *Metaphors we live by.* Chicago London.

Langacker, R. W. 1986. An introduction to cognitive grammar. *Cognitive science,* 10(1), 1-40.

Lautenschutz, A. K., 2012. *Assessing the Relevance of Context for Visualizations of Movement Trajectories.* (PhD Thesis). University of Zurich.

Lebiere, C., Anderson, J. R. and Bothell, D., 2001. Multi-tasking and cognitive workload in an ACT-R model of a simplified air traffic control task. *Proceedings of the 10th Conference on Computer Generated Forces and Behavior Representation*, May 15–17, Norfolk, VA.

Lewis, R. 1999. Cognitive modeling, symbolic. *The MIT encyclopedia of the cognitive sciences*, 525-527.

Li, Z. and Huang, P. 2002. Quantitative measures for spatial information of maps. *International Journal of Geographical Information Science,* 16(7), 699-709.

Lloyd, R., 1997. *Spatial Cognition: Geographic Environments.* Kluwer Academic Publishers.

Lloyd, R. and Bunch, R. L. 2003. Technology and Map-Learning: Users, Methods, and Symbols. *Annals of the Association of American Geographers,* 93(4), 828-850.

Loecher, M. and Jebara, T., 2009. CitySense: Multiscale Space Time Clustering of GPS Points and Trajectories. *Proceedings of the Joint Statistical Meeting*, August 1-6, Washington DC.

Lohrenz, M. C., Trafton, J. G., Beck, M. R. and Gendron, M. L. 2009. A Model of Clutter for Complex, Multivariate Geospatial Displays. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 51(1), 90-101.

Lohse, G. L., Biolsi, K., Walker, N. and Rueter, H. H. 1994. A classification of visual representations. *Commun. ACM,* 37(12), 36-49.

Longley, P., Goodchild, M. F., Maguire, D. J. and Rhind, D. W., 2005. *Geographical information systems and science.* John Wiley & Sons Inc.

Looije, R., te Brake, G. M. and Neerincx, M. A., 2007. Usability engineering for mobile maps. *Proceedings of the 4th international conference on mobile technology, applications, and systems and the 1st international symposium on Computer human interaction in mobile technology*, September 10-12, Helsinki, Finland, 532-539.

MacEachren, A. M. 1982. The Role of Complexity and Symbolization Method in Thematic Map Effectiveness. *Annals of the Association of American Geographers,* 72(4), 495-513.

MacEachren, A. M. 1992. Visualizing uncertain information. *Cartographic perspectives,* 13(13), 10-19.

MacEachren, A. M., 1995. *How maps work: representation, visualization, and design*. Guilford Press.

MacEachren, A. M. and Ganter, J. H. 1990. A pattern identification approach to cartographic visualization. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 27(2), 64-81.

MacEachren, A. M. and Kraak, M. J. 2001. Research challenges in geovisualization. *Cartography and Geographic Information Science,* 28(1), 3-12.

MacEachren, A. M., Robinson, A., Hopper, S., Gardner, S., Murray, R., Gahegan, M. and Hetzler, E. 2005. Visualizing Geospatial Information Uncertainty: What We Know and What We Need to Know. *Cartography and Geographic Information Science,* 32(3), 139-161.

MacEachren, A. M., Roth, R. E., O'Brien, J., Li, B., Swingley, D. and Gahegan, M. 2012. Visual Semiotics & Uncertainty Visualization: An Empirical Study. *Visualization and Computer Graphics, IEEE Transactions on,* 18(12), 2496-2505.

Maglio, P. P. and Matlock, T., 1998. Metaphors we surf the web by. *Workshop on Personalized and Social Navigation in Information Space*, 16 - 17 March, Kista, Sweden.

Malaka, R. and Zipf, A., 2000. Deep Map-challenging IT research in the framework of a tourist information system. *Proceedings of ENTER 2000 - Information and Communication Technologies in Tourism*, Barcelona, Spain, 15-27.

Marchionini, G., 1997. *Information seeking in electronic environments.* Cambridge University Press.

McKelvie, S. J. 1978. Graphic rating scales: How many categories. *British Journal of Psychology,* 69(2), 185-202.

McMaster, R. B. and Usery, E. L., 2004. *A research agenda for geographic information science.* CRC Press.

McNamara, T. P., Rump, B. R. and Werner, S. 2003. Egocentric and geocentric frames of reference in memory of large-scale space. *Psychonomic Bulletin & Review,* 10(3), 589-595.

Mei, Y. and Li, L., 2008. A cartographic data model for better geographical visualization based on knowledge. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*, 3 -11 July, Bejing, China, 611-616.

Meine, K. H. 1977. Cartographic communication links and a cartographic alphabet. *Cartographica,* 14(1), 72.

Meng, L., 2003. About the emotional requirements of map users. *In:* Wolodtschenko, H. and Schlichtmann, A. eds. *Diskussionsbeiträge zur Kartosemiotik und zur Theorie der Kartographie,.* Dresden: TU Dresden., 27 - 34.

Meng, L., 2008. The State of the Art of Map-Based Mobile Services. *In:* Meng, L., Zipf, A. and Winter, S. eds. *Map-based Mobile Services.* Springer, 1-12.

Mennis, J. L., Peuquet, D. J. and Qian, L. 2000. A conceptual framework for incorporating cognitive principles into geographical database representation. *International Journal of Geographical Information Science,* 14(6), 501-520.

Miller, G. A. 1956. The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological review,* 63(2), 81.

Miller, H. J., 2004. Activities in Space and Time. *In:* P. Stopher, Button, K., Haynes, K. and Hensher, D. eds. *Handbook of Transport 5: Transport Geography and Spatial Systems.* Pergamon/Elsevier Science.

Miller, H. J. 2005. A Measurement Theory for Time Geography. *Geographical Analysis,* 37(1), 17-45.

Moellering, H., 2003. Possibilities for a general theory of spatial data. *Proceedings of the 21st International Cartographic Conference*, 10-16 August, Durban, South Africa:, 1895–1901.

Montello, 1993. Scale and Multiple Psychologies of Space. *In:* Frank, A. U. and Campari, I. eds. *Spatial Information Theory A Theoretical Basis for GIS.* Berlin Heidelberg: Springer, 312--321.

Montello, D. R., Goodchild, M. F., Gottsegen, J. and Fohl, P. 2003. Where's Downtown?: Behavioral Methods for Determining Referents of Vague Spatial Queries. *Spatial Cognition & Computation,* 3(2-3), 185--204.

Mountain, D. and MacFarlane, A. 2007. Geographic information retrieval in a mobile environment: evaluating the needs of mobile individuals. *Journal of Information Science,* 33(5), 515-530.

Mountain, D. M., 2005. *Exploring mobile trajectories.* (PhD Thesis). City University.

Mountain, D. M., 2007. Spatial filters for mobile information retrieval. *Proceedings of the 4th ACM workshop on Geographical information retrieval*, November 9, Lisbon, Portugal, 61-62.

Nardi, B. A., 1995. Studying context: a comparison of activity theory, situated action models, and distributed cognition. *In:* Nardi, B. A. (ed.) *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: MIT, 69-102.

Nardi, B. A., 1996. Activity theory and human-computer interaction. *In:* Nardi, B. A. (ed.) *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: MIT Press, 7-16.

Naumann, A., Hurtienne, J., Israel, J., Mohs, C., Kindsmüller, M., Meyer, H. and Hußlein, S., 2007. Intuitive Use of User Interfaces: Defining a Vague Concept. *In:* Harris, D. (ed.) *Engineering Psychology and Cognitive Ergonomics.* Springer Berlin Heidelberg, 128-136.

Navarro-Prieto, R., Scaife, M. and Rogers, Y., 1999. Cognitive strategies in web searching. *Proceedings of the 5th Conference on Human Factors & the Web*, June 1999, Gaithersburg, MD: National Institute of Standards and Technology, 43-56.

Navratil, G. and Grum, E., 2007. What makes Location-Based Services fail? *In:* Gärtner, G., Cartwright, W. and Peterson, M. P. eds. *Location Based Services and Telecartography.* Springer, 59 - 73.

Neumann, A., 2005. Thematic Navigation in Space, Time and Topic. *Proceedings of the 22nd International Cartographic Conference*, 9-16 July, A Coruna, Spain.

Neutens, T., Schwanen, T. and Witlox, F. 2011. The Prism of Everyday Life: Towards a New Research Agenda for Time Geography. *Transport Reviews: A Transnational Transdisciplinary Journal,* 31(1), 25 - 47.

Nielsen, J., 1993. *Usability engineering.* Morgan Kaufmann.

Nielsen, J., 2002. *Ten usability heuristics* [online]. Available from: http://www.useit.com/papers/heuristic/heuristic_list.html, [Accessed 7th March 2012].

Nivala, A.-M. and Sarjakoski, T. L. 2007. User Aspects of Adaptive Visualization for Mobile Maps. *Cartography and Geographic Information Science,* 34(4), 275-284.

Nivala, A. and Sarjakoski, T., 2003a. Need for Context-Aware Topographic maps in Mobile Devices. *9th Scandinavian Research Conference on Geographic Information Science ScanGIS*, June 4-6, Espoo, Finland, 15-29.

Nivala, A. M. and Sarjakoski, L. T., 2003b. An Approach to Intelligent Maps: Context Awareness. *Proceedings of the workshop W1 "HCI in Mobile Guides 2003". In conjunction with: Fifth International Symposium on Human Computer Interaction with Mobile Devices and Services*, September 8-11, Udine, Italy, 45-50.

Nivala, A. M., Sarjakoski, T., Laakso, K., Itaranta, J. and Kettunen, P., 2008. User Requirements for Location-Based Services to Support Hiking Activities. *Location Based Services and Telecartography II.* Springer, 167 - 184.

Norman, D., 2002. *The design of everyday things.* Basic Books, New York.

Norman, D. A., 1986. Cognitive engineering. *In:* Norman, D. A. and Draper, S. W. eds. *User centered system design.* Hillsdale, NJ: Lawrence Erlbaum Associates, 31-61.

Norman, D. A., 1991. Cognitive artifacts. *In:* Carroll, J. M. (ed.) *Designing interaction: Psychology at the human-computer interface.* New York: Cambridge University Press, 17–38.

Norman, D. A. 1993. Cognition in the head and in the world: An introduction to the special issue on situated action. *Cognitive science,* 17(1), 1-6.

Norman, D. A. 1999. Affordance, conventions, and design. *interactions,* 6(3), 38-43.

Nurminen, A., 2006. m-LOMA-a mobile 3D city map. *Proceedings of WEB3D 2006,* April 18-21, 2006, Columbia, Maryland, 7-18.

Ogawa, Y., Morita, T. and Kobayashi, K. 1991. A fuzzy document retrieval system using the keyword connection matrix and a learning method. *Fuzzy sets and systems,* 39(2), 163-179.

Oinas-Kukkinen and Kurkela, 2003. Developing Successful Mobile Applications. *Proceedings Computer Science and Technology (CST 2003)*, May 19 – 21, 2003, Cancun, Mexico.

Olivieri, M., 2012. *Visualisierung Geografischer Relevanz auf kleinen Displays.* (MSc Thesis). University of Zurich.

Oulasvirta, A., 2004. *Human-Computer Interaction in Mobile Context : A Cognitive Resources Perspective.* (Licentiate Thesis). University of Helsinki.

Oulasvirta, A., Estlander, S. and Nurminen, A. 2009a. Embodied interaction with a 3D versus 2D mobile map. *Personal Ubiquitous Comput.,* 13(4), 303-320.

Oulasvirta, A., Hukkinen, J. P. and Schwartz, B., 2009b. When more is less: the paradox of choice in search engine use. *Proceedings of the 32nd international ACM SIGIR conference on Research and development in information retrieval*, July 19 - 23, Boston, MA, 516-523.

Oulasvirta, A., Tamminen, S., Roto, V. and Kuorelahti, J., 2005. Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. *Proceedings of the SIGCHI conference on Human factors in computing systems*, April 2 - 7, Portland, OR, 919-928.

Oviatt, S. 1997. Mulitmodal Interactive Maps: Designing for Human Performance. *Human-Computer Interaction,* 12(2), 93.

Ozcan, R., Altingovde, I. S. and Ulusoy, O. 2011. Exploiting navigational queries for result presentation and caching in Web search engines. *Journal of the American Society for Information Science and Technology,* 62(4), 714-726.

Paas, F., Renkl, A. and Sweller, J. 2003. Cognitive load theory and instructional design: Recent developments. *Educational Psychologist,* 38(1), 1-4.

Payne, J. W., Bettman, J. R. and Johnson, E. J., 1990. The adaptive decision maker: Effort and accuracy in choice. *Insights in decision making: A tribute to Hillel J. Einhorn.* Chicago, IL: University Of Chicago Press, 129-153.

Perugini, S. 2010. Supporting multiple paths to objects in information hierarchies: Faceted classification, faceted search, and symbolic links. *Information processing & management,* 46(1), 22-43.

Peuquet, D. J. 2001. Making space for time: Issues in space-time data representation. *GeoInformatica,* 5(1), 11-32.

Peuquet, D. J., 2002. *Representations of space and time.* New York: The Guilford Press.

Pombinho, P. M., Carmo, M. B. and Afonso, A. P., 2009. Evaluation of Overcluttering Prevention Techniques for Mobile Devices. *13th International Conference on Information Visualisation*, July 15-July 17, Barcelona, Spain, 127-134.

Popova, Y., 2005. Image schemas and verbal synaesthesia. *In:* Hampe, B. (ed.) *From perception to meaning: image schemas in cognitive linguistics.* Berlin: Mouton de Gruyter, 395-419.

Poppe, E. L., van Elzakker, C. P. J. M. and Stoter, J. E., 2006. Towards a method for automated task-driven generalization of base maps. *Proceedings of UDMS '06, 25th Urban Data Management Symposium*, May 15-17, Aalborg, Denmark, 351–364.

Preston, C. C. and Colman, A. M. 2000. Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica,* 104(1), 1-15.

Raper, J. 2007. Geographic Relevance. *Journal of Documentation,* 63(6), 836-852.

Raper, J., Dykes, J., Wood, J., Mountain, D., Krause, A. and Rhind, D. 2002. A framework for evaluating geographical information. *Journal of Information Science,* 28(1), 39-50.

Raper, J., Gartner, G., Karimi, H. and Rizos, C. 2007. Applications of location–based services: a selected review. *Journal of Location Based Services,* 1(2), 89-111.

Raubal, M., 1998. *Agent-based simulation of human wayfinding: A perceptual model for unfamiliar buildings.* (PhD Thesis). Vienna University of Technology.

Raubal, M. 2009. Cognitive Engineering for Geographic Information Science. *Geography Compass,* 3(3), 1087-1104.

Raubal, M., Miller, H. and Bridwell, S. 2004. User-Centred Time Geography for Location-Based Services. *Geografiska Annaler,* 86(4), 245-265.

Raubal, M. and Panov, I., 2009. A Formal Model for Mobile Map Adaptation. *In:* Gartner, G. and Rehrl, K. eds. *Location Based Services and Telecartography II.* Springer Berlin Heidelberg, 11-35.

Reichenbacher, T., 2003. Adaptive Methods for Mobile Cartography. *Proceedings of the 21st International Cartographic Association*, 10-16 August, Durban, South Africa, 230 - 249.

Reichenbacher, T., 2004. *Mobile Cartography - Adaptive Visualisation of Geographic Informaiton on Mobile Devices.* Munich, Germany: Verlag Dr. Hut.

Reichenbacher, T., 2005a. Adapted ego-maps for mobile users. *In:* Meng, L., Reichenbacher, T. and A, Z. eds. *Map-based Mobile Services.* Springer Berlin Heidelberg, 141-150.

Reichenbacher, T., 2005b. The Importance of Being Relevant. *CD-ROM proceedings of ICC 2005 – International Cartographic Conference*, July 9-16, A Coruna, Spain.

Reichenbacher, T., 2007. Adaption in mobile and ubiquitous cartography. *In:* Cartwright, W., Peterson, M. P. and Gartner, G. eds. *Multimedia Cartography.* Heidelberg: Springer Verlag, 383-397.

Reichenbacher, T., 2009a. Die Bedeutung der Relevanz für die Räumliche Wissensgewinnung. *In:* Kriz, K., Kainz, W. and Riedl, A. eds. *Geokommunikation im Umfeld der Geographie, Wiener Schriften zur Geographie und Kartographie.* Vienna, 85-90.

Reichenbacher, T., 2009b. Geographic relevance in mobile services. *Proceedings of the 2nd International Workshop on Location and the Web*, April 4, Boston, Massachusetts.

Reichenbacher, T., De Sabbata, S. and Crease, P., 2009. Concept of Geographic Relevance. *LBS 2009 - Proceedings of the 6th International Symposium on LBS & TeleCartography.*, 2 September- 4 September, Nottingham, UK.

Reichenbacher, T. and Swienty, O., 2007. Attention-Guiding Geovisualisation. *AGILE International Conference on Geographic Information Science*, May 8 -11, Aalborg University, Denmark.

Rescorla, M. 2008. Predication and cartographic representation. *Synthese,* 169(1), 175-200.

Ricci, F., Cavada, D. and Nguyen, Q. N., 2002. Integrating travel planning and on-tour support in a case-based recommender system. *Proceedings of the Workshop on Mobile Tourism Systems*, 17th September, Pisa, Italy, 11-16.

Riegelsberger, J. and Nakhimovsky, Y., 2008. Seeing the bigger picture: a multi-method field trial of google maps for mobile. *CHI '08 extended abstracts on Human factors in computing systems*, Florence, Italy, 2221-2228.

Rieser, J. J. 1989. Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 15(6), 1157.

Rinner, C. and Raubal, M. 2005. Personalized multi-criteria decision strategies in location-based decision support. *International Journal of Geographic Information Sciences,* 11(1), 61-68.

Rinner, C., Raubal, M. and Spigel, B., 2005. User interface design for location-based decision services. *13th International Conference on GeoInformatics*, August 17 – 19, Toronto, Canada.

Risch, J. S., 2008. *On the role of metaphor in information visualization* [online]. Pacific Northwest National Laboratory, Richland, Washington, U.S.A. . Available from: http://arxiv.org/pdf/0809.0884.pdf [Accessed 01.02.2012.

Robinson, A. H., 1995. *Elements of cartography.* New York: Wiley.

Rong, T., William, M. S. J. and Jack, L. V. 1999. Towards the identification of the optimal number of relevance categories. *Journal of the American Society for Information Science,* 50(3), 254-264.

Rosenholtz, R., Li, Y. and Nakano, L. 2007. Measuring visual clutter. *Journal of Vision,* 7(2), 17.

Rüetschi, U. J. and Timpf, S., 2004. Schematic geometry of public transport spaces for wayfinding. *In:* Raubal, M., Sliwinski, A. and Kuhn, W. eds. *Geoinformation und Mobilität.* IfGI Prints, 191-203.

Ryan, H. and Janet, W., 2008. Using mobile preference-based searching to improve tourism decision support. *Proceedings of the 2008 annual research conference of the South African Institute of Computer Scientists and Information Technologists on IT research in developing countries: riding the wave of technology*, October 6 - 8, Wilderness, South Africa.

Salovaara, A., 2004. Proactive Reasoning in Mobile HCI: Tackling Uncertainty and Appropriate Task Support. *HIIT Technical Report 2004-2.*

Saracevic, T., 1996. Relevance reconsidered. *In:* Ingewersen, P. and Pors, N. O. eds. *Information science: Integration in perspectives.* Copenhagen: The Royal School of Librarianship, 201-218.

Saracevic, T., Kantor, P., Chamis, A. Y. and Trivison, D. 1997. A study of information seeking and retrieving: Background and methodology. *Journal of the American Society for Information Science,* 39(3), 161-176.

Sarjakoski, L. T. and Nivala, A. M., 2005. Adaptation to Context–A Way to Improve the Usability of Mobile Maps. *In:* Reichenbacher, T., Zipf, A. and Meng, L. eds. *Map-based Mobile Services.* NY: Springer, 107-123.

Sarjakoski, T., Sester, M., Harrie, L., Hampe, L. L. L. and Koivula, T., 2005. Web Generalisation Services in GiMoDig - towards a standardised service real-time generalisation.

Conference Proceedings, AGILE 2005, 8th conference on Geographic Information Science, May 26-28, Estoril, Protugal, 509 - 518.

Sarkar, M., Snibbe, S. S., Tversky, O. J. and Reiss, S. P., 1993. Stretching the rubber sheet: a metaphor for viewing large layouts on small screens. *Proceedings of the 6th annual ACM symposium on User interface software and technology*, October 25-26, Atlanta, Georgia, United States, 81-91.

Scaife, M. and Rogers, Y. 1996. External cognition: how do graphical representations work. *International Journal of Human-Computer Studies,* 45(4), 185-213.

Schilit, B. N., Trevor, J., Hilbert, D. M. and Koh, T. K. 2002. Web interaction using very small internet devices. *Computer,* 35(10), 37-45.

Schmidt, A., Beigl, M. and Gellersen, H. 1999. There is more to context than location. *Computers and Graphics*, 23(6), 893--901.

Schmiedl, G., Blumenstein, K. and Seidl, M., 2011. Usability Testing for Mobile Scenarios of Fragmented Attention. *CHI Sparks*, 23 June, 2011, HAN University of Applied Sciences, Arnhem, Netherlands.

Schwanen, T., Dijst, M. and Kwan, M.-P. 2008a. ICTS and the decoupling of everyday activities, space and time: introduction. *Tijdschrift voor economische en sociale geografie,* 99(5), 519-527.

Schwanen, T. and Kwan, M.-P. 2008. The Internet, mobile phone and space-time constraints. *Geoforum*, 39(3), 1362-1377.

Schwanen, T., Kwan, M.-P. and Ren, F. 2008b. How fixed is fixed? Gendered rigidity of space-time constraints and geographies of everyday activities. *Geoforum,* 39(6), 2109-2121.

Seifert, I., Barkowsky, T. and Freksa, C., 2007. Region-based representation for assistance with spatio-temporal planning in unfamiliar environments. *Location Based Services and Telecartography.* Springer, 179-191.

Shah, P., Mayer, R. E. and Hegarty, M. 1999. Graphs as Aids to Knowledge Construction: Signaling Techniques for Guiding the Process of Graph Comprehension. *Journal of Educational Psychology,* 91(4), 690-702.

Shneiderman, B., 1989. Designing the user interface. *Computers in the human context: information technology, productivity, and people.* MIT Press, 166-173.

Shneiderman, B., 1996. The eyes have it: a task by data type taxonomy for information visualizations. *Proceedings of IEEE Symposium on Visual Languages*, Los Alamos, CA, 336-343.

Simon, H., Dantzig, G., Hogarth, R., Plott, C., Raiffa, H., Schelling, T., Shepsle, K., Thaler, R., Tversky, A. and Winter, S. 1987. Decision making and problem solving. *Interfaces,* 17(5), 11-31.

Simon, H. A., 1969. *The science of the artificial.* Cambridge, MA: MIT press.

Simon, H. A., 1972. Theories of bounded rationality. *In:* McGuire, C. and Radner, R. eds. *Decision and organization.* North Holland, Amsterdam, 161-176.

Skov-Petersen, H., 2001. Estimation of distance-decay parameters: GIS-based indicators of recreational accessibility. *The 8th Scandinavian Research Conference on Geographical Information Science.*, June 24-27, Aas, Norway, 237-258.

Skupin, A. and Fabrikant, S. I. 2003. Spatialization Methods: A Cartographic Research Agenda for Non-geographic Information Visualization. *Cartography and Geographic Information Science,* 30(2), 99-119.

Slocum, T. A., Blok, C., Jiang, B., Koussoulakou, A., Montello, D. R., Fuhrmann, S. and Hedley, N. R. 2001. Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science,* 28(1), 61-75.

Sluter, R. S. 2009. New theoretical research trends in cartography. *Revista Brasileira de Cartografia,* (53), 29-37.

Smith, B. and Mark, D. M. 2001. Geographical categories: an ontological investigation. *International Journal of Geographical Information Science,* 15(7), 591-612.

Smith, B. and Varzi, A. C. 2000. Fiat and bona fide boundaries. *Philosophy and phenomenological research,* 60(2), 401-420.

Smith, D. C., Irby, C., Kimball, R., Verplank, W. and Harslem, E., 1987. Designing the Star user interface. 653-661.

Sohn, T., Li, K. A., Griswold, W. G. and Hollan, J. D., 2008. A diary study of mobile information needs. *Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, April 5 - 10, Florence, Italy, 433-442.

Spink, A., Greisdorf, H. and Bateman, J. 1998. From highly relevant to not relevant: examining different regions of relevance. *Information Processing and Management,* 34(5), 599-621.

Stock, W. G. 2006. On relevance distributions. *Journal of the American Society for Information Science and Technology*, 57(8), 1126-1129.

Sutcliffe, A., Ennis, M. and Hu, J. 2000. Evaluating the effectiveness of visual user interfaces for information retrieval. *International Journal of Human-Computer Studies*, 53(5), 741-763.

Swienty, O., 2008. *Attention-Guiding Geovisualisation.* (PhD Thesis). Technical University Munich.

Swienty, O., Jahnke, M., Kumke, H. and Reppermund, S., 2008a. Effective visual scanning of geographic information. *Visual 2008*, September 11 - 12, Salermo, Italy, 19-30.

Swienty, O., Reichenbacher, T., Reppermund, S. and Zihl, J. 2008b. The role of relevance and cognition in attention-guiding geovisualisation. *Cartographic Journal*, 45(3), 227 - 238.

Teo, L. and John, B. E., 2006. Comparisons of keystroke-level model predictions to observed data. *CHI '06 extended abstracts on Human factors in computing* 22-27 April, 2006, Quebec, Canada, 1421-1426.

Teo, L. and John, B. E., 2008. Cogtool-Explorer: towards a tool for predicting user interaction. *CHI '08 extended abstracts on Human factors in computing systems*, April 5 - 10, Florence, Italy, 2793-2798.

Thomas, J. J. and Cook, K. A. 2006. A visual analytics agenda. *IEEE Computer Graphics and Applications,* 26(1), 10-13.

Thomas, M. and Morwitz, V. 2008. Heuristics in Numerical Cognition: Implications for Pricing. *Handbook of Research in Pricing*, 1(8).

Thrift, N., 1977. An introduction to time geography. *Geo Abstracts*, Norwich: University of East Anglia

Timpf, S., 1999. Abstraction, levels of detail, and hierarchies in map series. *In:* Freksa, C. and Mark., D. M. eds. *Spatial Information Theory. Cognitive and Computational Foundations of Geographic Information Science.* Berlin-Heidelberg: Springer Lecture Notes in Computer Science 1661, 125-140.

Timpf, S., 2003. Geographic activity models. *In:* M., D., M., G. and F., W. M. eds. *Foundations of Geographic Information Science. London, Taylor and Francis.* London: Taylor and Francis, 241–254.

Tomaszewski, B., 2007. Local Model Semantics, Categories, and External Representation: Towards a Model for Geo-historical Context. *Sixth International and Interdisciplinary Conference on Modeling and Using Context*, 20 September, Roskilde University, Denmark.

Tong, C. C. and Chen, S. P., 2000. A study of en-route dynamic route choice behavior under the influence of traffic information. *Proceedings of the 7th World Congress on Intelligent Systems*, 6-9 November, Turin, Italy, 6-9.

Trieschnigg, D., Pezik, P., Lee, V., De Jong, F., Kraaij, W. and Rebholz-Schuhmann, D. 2009. MeSH Up: effective MeSH text classification for improved document retrieval. *Bioinformatics,* 25(11), 1412-1418.

Tuan, Y. F., 1979. Space and place: humanistic perspective. *In:* Gale, S. and Olsson, G. eds. *Philosophy in Geography.* Dordrecht: Reidel, 387-427.

Tufte, E. R. 1985. The visual display of quantitative information. *Applied Optics,* 24(2).

Tversky, B., 2005. Functional Significance of Visuospatial Representations. *In:* Shah, P. (ed.) *The cambridge handbook of visuospatial thinking.* Cambridge: Cambridge University Press, 1-34.

Tversky, B. and Lee, P. U., 1999. Pictorial and Verbal Tools for Conveying Routes. *Proceedings of the International Conference on Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science*, August 25-29, Stade, Germany, 51 - 64.

Tversky, B., Zacks, J., Lee, P. and Heiser, J., 2000. Lines, blobs, crosses and arrows: Diagrammatic communication with schematic figures. *In:* Anderson, M., Cheng, P. and Haarslev, V. eds. *Theory and application of diagrams.* Berlin Heidelberg: Springer, 221-230.

Uttal, D. H. 2000. Seeing the big picture: Map use and the development of spatial cognition. *Developmental Science,* 3(3), 247-264.

Vaananen, K. and Schmidt, J., 1994. User interfaces for hypermedia: how to find good metaphors? *CHI '94 conference companion on Human factors in computing systems*, April 24-28, 1994, Boston, Massachusetts, USA, 263-264.

van der Heijden, H. 2006. Mobile decision support for in-store purchase decisions. *Decision Support Systems,* 42(2), 656-663.

Van Oosterom, P. J. M., 2007. Usable and well scaled maps for consumers. *Space for Geo-information: Project Report RGI-233.* Delft, Netherlands: ITC.

van Wijk, J. J. and Nuij, W. A. A., 2003. Smooth and efficient zooming and panning. *Information Visualization, 2003. INFOVIS 2003. IEEE Symposium on*, 21-21 Oct. 2003, 15-23.

Voudouris, V., Wood, J., Fisher, P. and Square, N., 2005. Collaborative Geovisualization: Object-Field Representations with Semantic and Uncertainty Information. *In:* Meersman, R., Tari, Z. and Herrero, P. eds. *On the Move to Meaningful Internet Systems 2005: Lecture Notes in Computer Science (LNCS).* Berlin: Springer.

Wang, D. and Cheng, T. 2001. A spatio-temporal data model for activity-based transport demand modelling. *International Journal of Geographical Information Science,* 15(6), 561-585.

Wilkening, J. and Fabrikant, S., 2011. How do decision time and realism affect map-based decision making? In: Hamhoum, F. and Kray, C., *COSIT'11 Proceedings of the 10th international conference on Spatial information theory*, September 12-16, Belfast, ME, USA, 1-19.

Wilson, T. D. 1997. Information behaviour: An interdisciplinary perspective. *Information Processing and Management,* 33(4), 551-572.

Winter, S. and Tomko, M., 2004. Shifting the Focus in Mobile Maps. *Joint Workshop on Ubiquitous, Pervasive and Internet Mapping UPIMap2004*, 7-9 September, Tokyo, Japan, 153--165.

Wolfe, J. M. 1994. Guided search 2. 0. A revised model of visual search. *Psychonomic Bulletin & Review,* 1(2), 202-238.

Wolfe, J. M., Butcher, S. J., Lee, C. and Hyle, M. 2003. Changing your mind: on the contributions of top-down and bottom-up guidance in visual search for feature singletons. *Journal of Experimental Psychology: Human Perception and Performance,* 29(2), 483.

Wood, M. 2001. The 21st Century World-No Future without Cartography. *Journal of Geospatial Engineering,* 3(2), 77-86.

Woods, D. D., 1991. Representation aiding: a ten year retrospective. *1991 IEEE International Conference on Systems, Man, and Cybernetics*, 13 - 16 October, Charlottesville, Virginia, 1173-1176.

Wunderlich, M. and Auer, M., 2008. Perspective maps in mobile devices–just style or proper function? *5th International Symposium on LBS & TeleCartography*, 26th - 28th November, Salzburg, Austria.

Yu, B. and Cai, G., 2010. Using Intentions and Plans of Mobile Activities to Guide Geospatial Web Service Composition. *Services Computing Conference (APSCC), 2010 IEEE Asia-Pacific*, December 10 - 12, 141-148.

Yuan, M., Mark, D. M., Egenhofer, M. J. and Peuquet, D. J., 2004. Extensions to geographic representation. *In:* McMaster, R. B. and Usery, E. L. eds. *A Research Agenda for Geographic Information Science.* Boca Raton, FL: CRC Press, 130-156.

Zadeh, L. A. 1965. Fuzzy sets. *Information and Control,* 8(3), 338–353.

Zenghong, W. and Yufen, C., 2009. Context Awareness and Modeling in Sef-Adaptive Geo-Information Visualization. *ICC2009*, November 15-21, Santiago, Chile.

Zhang, J. 1997. The nature of external representations in problem solving. *Cognitive science,* 21(2), 179-217.

Zhang, J. and Norman, D. A. 1994. Representations in distributed cognitive tasks. *Cognitive science,* 18(1), 87-122.

Zhumagulova, R., Mountain, D. M. and Rhin, C., 2007. Evaluating location-based functionality from the perspective of the user: a case study from the Greenwich Observatory. *Geocomputation 2007*, 3-5 September, National University of Ireland, Maynooth, Ireland.

Ziemkiewicz, C. and Kosara, R. 2008. The shaping of information by visual metaphors. *Visualization and Computer Graphics, IEEE Transactions on,* 14(6), 1269-1276.

Zipf, A. and Jöst, M. 2006. Implementing adaptive mobile GI services based on ontologies: Examples from pedestrian navigation support. *Computers, Environment and Urban Systems,* 30(6), 784-798.

Zipf, A. and Richter, F. 2002. Using Focus Maps to Ease Map Reading. *Artificial Intelligence/Künstliche Intelligenz. Special Issue:Spatial Cognition*, 4(2), 35–37.

Appendix I

Close-Distant
close relevance
closely relevant
distantly relevant
distant relevance

Large-Small
largely relevant
small relevance
little relevance
great relevance
little bit relevant
small relevance
medium relevance

Hot-Cold
hotly relevant
coldly relevant
hot relevance
cold relevance

Full-Empty
fully relevant
full relevance
empty relevance
emptily relevant

Part-Whole
wholly relevant
partly relevant
part relevance
whole relevance

Strong-Weak
strongly relevant
weakly relevant
strong relevance
weak relevance

High-Low
low relevance
high relevance
highly relevant

Hedge
very relevant
extremely relevant
extreme relevance
quite relevant
more relevant
more relevance
less relevance
less relevant
fairly relevant
fair relevance
not so relevant
much relevant
much relevance
some relevance

Appendix II

Order	Stimulus sequence		
1	V1	O2	S3
2	O3	S1	V2
3	S2	V3	O1
4	V2	S1	O3
5	O1	S2	V3
6	O2	V1	S3
…	…	…	…

Latin Square for Experiment I showing the proposed permutations of stimuli sequence among participants (V=colour value S=colour saturation O=opacity)

Order	Stimulus sequence				
1	FULLEMPTY	HIGHLOW	HOTCOLD	LIGHTDARK	OPACITY
2	OPACITY	FULLEMPTY	HIGHLOW	HOTCOLD	LIGHTDARK
3	LIGHTDARK	OPACITY	FULLEMPTY	HIGHLOW	HOTCOLD
4	HOTCOLD	LIGHTDARK	OPACITY	FULLEMPTY	HIGHLOW
5	HIGHLOW	LIGHTDARK	HOTCOLD	HIGHLOW	OPACITY
…	…	…	…	…	

Latin Square for Experiment II showing the five permutations of stimuli sequence

Appendix III

Based on the above screenshot, arrange the list below with what you believe to be the most relevant Cafe at the top and the least relevant at the bottom.

Please put the list in order. Just drag and drop using your mouse.

Your Ranking

A

B

C

D

E

Appendix IV

Cond-ition	Opacity	Origin	Desti-nation	Route	Arrow Along Route	Direction Arrow	Orientation	OP	OR	EXP1	EXP2	EXP3	EXP4
1	1							•	•	•			
2	1	1						•	•	•	•		
3	1	1				1		•	•				
4	1	1	1					•	•		•	•	
5	1	1	1	1				•	•			•	•
6	1	1	1	1	1			•	•				•
7	1	1	1			1		•	•			•	
8	1						1	•	•	•			
9	1	1					1	•	•	•	•		
10	1	1				1	1	•	•				
11	1	1	1				1	•	•		•	•	
12	1	1	1	1			1	•	•			•	•
13	1	1	1	1	1		1	•	•				•
14	1	1	1			1	1	•	•			•	
15		1				1		•	•				
16		1	1					•	•			•	
17		1	1	1				•	•			•	•
18		1	1	1	1			•	•				•
19		1	1			1		•	•			•	
20		1				1	1	•	•				
21		1	1				1	•	•			•	
22		1	1	1			1	•	•			•	•
23		1	1	1	1		1	•	•				•
24		1	1			1	1	•	•			•	

OP: Opacity Test, OR: Orientation Test, EXP1 Explicitness Test 1, EXP2: Explicitness Test 2, EXP3: Explicitness Test 3, EXP4: Explicitness Test 4 (• = included in analysis)

Appendix V

Imagine the following scenario:

You are at the Cinema to watch a film. After the film finishes, you have a table booked at a restaurant nearby where you have arranged to meet some friends. The arranged meeting time is 20:00 and the current time is 19:45, it takes 10 minutes to walk to the restaurant from your current location. You therefore do not have much time and need to find an ATM that is located in your direction of travel between your current location and that of the restaurant where you must meet your friends. The aim is to ***find an ATM that minimises the total distance you would have to travel****.*

To help you solve this problem you have a state-of-the-art map application that you can use to find an ATM. This map application can access your calendar and discover where you need to be and at what time. Using this information allows it to find ATMs that are located along your future path and able to provide you with money (i.e. they are not broken or closed). In the example above, this application would be able to discover ATMs located in the direction of the restaurant.

To aid your search, these ATMS are displayed on a map for you so that you can decide which one is most relevant to you. The application performs the search and returns the ten most relevant ATMs, these ATMs will be symbolised with a red circle on the map. An example of this symbol is shown below.

Clicking on an object with the left mouse button will select it, When they are selected they will turn from red to blue. Only one object can be selected at one time. The aim will always be to find the most relevant object based on the information given above. Although you will be timed it is asked that you keep in mind that you should focus on finding what you believe to be the most relevant object and not to make a decision as quickly as possible. When you are ready to begin the experiment press the continue button below, you will then be shown the first task. Between each task you will be returned to this scenario web page, so do not worry about trying to remember the information on this page, it will always be available to you before each task.

ATM Symbol

Selected ATM symbol